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OMEGA JAPAN ANTENNA SYSTEM: MODIFICATION AND VALIDATION TESTS. --ETC(U)
OCT 79 J C HANSELMAN N00123-78-C-0043

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OMEGA JAPAN ANTENNA SYSTEM: MODIFICATION AND VALIDATION TESTS

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(10) J. C. Hanselman, Megatek Corp. (11)

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ADMINISTRATIVE INFORMATION

Electronic measurements were performed on the OMEGA Japan Antenna System during the months of October and November 1978. The work was performed under NOSC Project MP01538B10 with Megatek Corporation as contractor under NOSC Contract N00123-78-C-0043, Task 014.

Volume 1 is the report proper. Volume 2 contains data sheets.

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Electromagnetic Propagation
Division

Under authority of
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Electronic measurements were performed on the OMEGA Japan antenna system during October-November 1978. The work was performed by Megatek Corporation under contract and by NOSC under Project MP01538B10. The electrical height of the antenna is 210 metres for all frequencies. The station will be able to radiate 10 kW with antenna currents of 360 amperes at 10.2 kHz to 270 amperes at 13.6 kHz. Recommendations are made regarding the gear ratios to use with the variometers.

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TABLES

I. INTRODUCTION

1. The work herein described was performed on and around the OMEGA Station Japan under Contract N00123-78-C-0043, technical agreement 532-014, by Megatek Corporation.

2. The tasks assigned were essentially in two different phases of work, as follows:

(a) To provide engineering and technical guidance to Japan Maritime Safety Agency (JMSA) contractor personnel during helix retapping for 11.05 kHz, antenna system measurements, and to optimize the antenna tuning gear ratios.

(b) Select and inspect sites for distance measuring equipment (DME), helicopter calibration and benchmark sites for field intensity measurements (FIM). Conduct FIM by helicopter and instruct JMSA personnel in the procedures for benchmark measurements.

3. Evaluate the data taken to determine the operational parameters of the OMEGA transmitter and antenna system.

4. The report is divided into two volumes. Volume 1 is the technical report and Appendices while Volume 2 contains the data sheets.

II. INSTALLATION OF THE FOURTH OMEGA FREQUENCY, 11.05 kHz

HELIX TAPPING

No consultation was sought and none was given.

ANTENNA SYSTEM MEASUREMENTS

1. No assistance was requested.

2. When the results of the antenna system resistance (R_{as}) were discussed the value seemed a bit high, based on the operating levels of the transmitter subsequent to measurements.

3. An unofficial baseline test was made with the transmitter operating into the dummy load, which provided a proper termination. This, in general, confirmed that the transmitter was operating into a proper load (R_{as}) - not a higher value.

4. It is suggested that at low power levels the insulators may be suffering from surface leakage; while at high power the insulators might be cleared of leakage.

All changes to the timing and control set were accomplished by JMSA personnel.

III. ANTENNA TUNING GEAR RATIO TESTS

INTRODUCTION

1. In order to design a gear box for the antenna tuning system, and to specify preliminary gear ratios that would perform on a number of widely different antennas, it was necessary to assume that:

(a) All of the capacitance was lumped at the top of the antenna.

(b) All of the inductance was lumped in the antenna tuning system.

(c) The variable inductance was linear with position over the entire range of its movement.

None of these assumptions are true in a real installation. However, the approximation is good enough to provide a base for further refinement.

2. The original gear ratios were based on ΔL required to retune a ΔC obtained from the equation $f = (2\pi\sqrt{LC})^{-1}$. An additional requirement was equal spacing of the ratios, above and below 1:1, which produced a ratio of 4/3 for 10.2 kHz and 3/4 for 13.6 kHz. This is a desirable concept to prevent absurd ratios but it is not always possible to achieve using sprockets having limiting values of size and number of teeth.

3. It must be assumed that the self-inductance of the antenna will remain virtually constant when the structure is distorted by winds, and

the variable causing a change in capacitance of the antenna can be simulated by addition of capacitance at the exit bushing of the helix house, or at the base insulator, the most accessible places.

TEST PROCEDURES

1. The procedure of appendix F: REV. 1 was used.

2. The capacitor spacing was adjusted to produce a cyclic change in main drive shaft position of approximately 20 turns when capacitance was added then removed.

3. Steps 3 through 11, of the procedures of Appendix F, were performed three times giving six values of "drive shaft rotation" for which a mean may be calculated. These data are recorded in table 1.

4. Using the format of Data Sheet F2 Rev. 1, of Appendix F, table 2 was prepared and the indicated calculations performed.

5. Each of the six installed gear boxes contained the number of sprockets, having the number of teeth indicated, shown in table 3. The totals available are also shown in table 3.

6. From this inventory of sprockets all available gear ratios were calculated and are shown in table 4.

7. Using the format of Data Sheet F4 Rev. 1, of Appendix F, table 5 is constructed giving the required gear ratios after selecting a set for 13.60 kHz, the nearest available ratio and the errors. Only two data lines are included in table 5 of the 18 data line calculations. The

TABLE 1. DRIVE SHAFT COUNTER READINGS, ANTENNA TUNING GEAR RATIO TESTS.

Freq. (kHz)	ΔC	Drive Shaft Counter Reading (Turns)	Drive Shaft Rotation (Turns)
10.20	OFF	87.8	
			23.1
	ON	110.9	
			23.0
	OFF	87.9	
			23.2
	ON	111.1	
			23.1
	OFF	88.0	
			23.2
	ON	111.2	
			23.0
	OFF	88.2	
		Mean drive shaft revolutions (MDSR)	23.10
11.05	OFF	91.6	
			22.4
	ON	114.0	
			22.5
	OFF	91.5	
			22.5
	ON	114.0	
			22.5
	OFF	91.5	
			22.5
	ON	114.0	
			22.5
	OFF	91.5	
		Mean drive shaft resolutions (MDSR)	22.48

TABLE 1. (cont)

Freq. (kHz)	ΔC	Drive Shaft Counter Reading (Turns)	Drive Shaft Rotation (Turns)
11-1/3	OFF	90.0	
			22.3
	ON	112.3	
			22.2
	OFF	90.1	
			22.2
	ON	112.3	
			22.2
	OFF	90.1	
			22.2
	ON	112.3	
			22.0
	OFF	90.3	
		Mean drive shaft revolutions (MDSR)	22.18
12.80	OFF	92.8	
			21.5
	ON	114.3	
			21.7
	OFF	92.6	
			21.7
	ON	114.3	
			21.7
	OFF	92.6	
			21.7
	ON	114.3	
			21.7
	OFF	92.6	
		Mean drive shaft revolutions (MDSR)	21.67

TABLE 1. (cont)

Freq. (kHz)	ΔC	Drive Shaft Counter Reading (Turns)	Drive Shaft Rotation (Turns)
13.60	OFF	89.0	
			21.0
	ON	110.0	
			21.1
	OFF	88.9	
			21.0
	ON	109.9	
			21.0
	OFF	88.9	
			21.2
	ON	110.1	
			21.2
	OFF	88.9	
		Mean drive shaft revolutions (MDSR)	21.08

TABLE 2. LEAD SCREW RATIO (LSR) CALCULATIONS.

Freq. (kHz)	MDSR (Turns)		Installed Gear Ratio (2)		LSR (Turns) (2)		LSR (Ref.) (1 & 2)		LSR Ratio Between Freqs. (2)
13.60	21.08	x	0.75000	=	15.81000	÷	15.81000	=	1.00000
12.80	21.67	x	0.84746	=	18.36446	÷	15.81000	=	1.16157
11-1/3	22.18	x	1.08000	=	23.95440	÷	15.81000	=	1.51514
11.05	22.48	x	1.13636	=	25.54537	÷	15.81000	=	1.61557
10.20	23.10	x	1.33333	=	30.79992	÷	15.81000	=	1.94813

Note 1. While any of the LSR values may be chosen as the reference, it is easier to use the value for 13.60 kHz in order to obtain ratios larger than 1.0 for the next step.

Note 2. Even though the precision of measurement does not warrant it, keep at least five or six significant figures to mimimize rounding errors.

TABLE 3. INVENTORY OF SPROCKETS.

Quantity (per box)	Size (No. of teeth)	Total (6 boxes)
1	33	6
3	36	18
2	44	12
1	48	6
2	50	12
2	54	12
1	59	6

TABLE 4. AVAILABLE GEAR RATIOS, EACH BOX.

Ratio	Sprockets (Teeth) In - Out	Ratio	Sprockets (Teeth) In - Out
0.55932	33 - 59	1.00000	50 - 50
0.61017	36 - 59	1.00000	54 - 54
0.61111	33 - 54	1.04167	50 - 48
0.66000	33 - 50	1.08000	54 - 50
0.66667	36 - 54	1.09091	36 - 33
0.68750	33 - 48	1.09091	48 - 44
0.72000	36 - 50	1.09259	59 - 54
0.74576	44 - 59	1.12500	54 - 48
0.75000	33 - 44	1.13636	50 - 44
0.75000	36 - 48	1.18000	59 - 50
0.81356	48 - 59	1.22222	44 - 36
0.81481	44 - 54	1.22727	54 - 44
0.81818	36 - 44	1.22917	59 - 48
0.84746	50 - 59	1.33333	44 - 33
0.88000	44 - 50	1.33333	48 - 36
0.88889	48 - 54	1.34091	59 - 44
0.91525	54 - 59	1.38889	50 - 36
0.91667	33 - 36	1.45455	48 - 33
0.91667	44 - 48	1.50000	54 - 36
0.92593	50 - 54	1.51515	50 - 33
0.96000	48 - 50	1.63636	54 - 33
1.00000	36 - 36	1.63889	59 - 36
1.00000	44 - 44	1.78788	59 - 33

TABLE 5. REQUIRED GEAR RATIO CALCULATION AND SELECTION.

Frequency (kHz)	13.60	12.80	11-1/3	11.05	10.20
LSR Ratio	1.00000	1.16157	1.51514	1.61557	1.94813
SET NUMBER 1					
Required Ratio	0.91667	1.06478	1.38888	1.48094	1.78579
Available Ratio		1.08000	1.38889	1.50000	1.78788
Error (%)	1.43 p-p	1.43	0.00	1.29	0.12
SET NUMBER 2					
Required Ratio	0.75000	0.87118	1.13636	1.21168	1.46110
Available Ratio		0.88000	1.13636	1.22222	1.45455
Error (%)	1.46 p-p	1.01	0.00	0.87	-0.45

remaining 16 all had significantly larger peak-to-peak errors so there is no useful purpose served by including them.

CONCLUSIONS

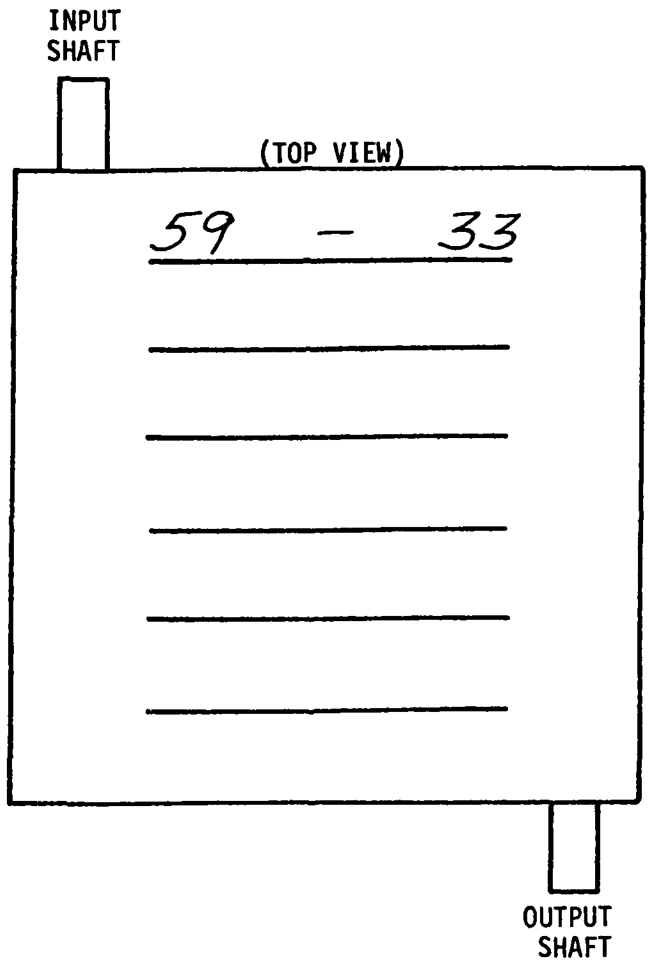
1. The two sets of gear ratios with the smallest peak-to-peak errors are shown in table 5. Set number 1 was selected to be installed. A set of gears for each frequency, plus a ratio of 1:1, are included in the spare variometer room. All six variometer room gear assignments are shown in Figures 1 through 6.

2. The peak-to-peak error should now be 1.43%.

3. Note any problems in tracking that may occur during the changing seasons. After all the stations have been tested and run for a year or two it might be beneficial to order sprockets that produce smaller errors, for all stations at one time.

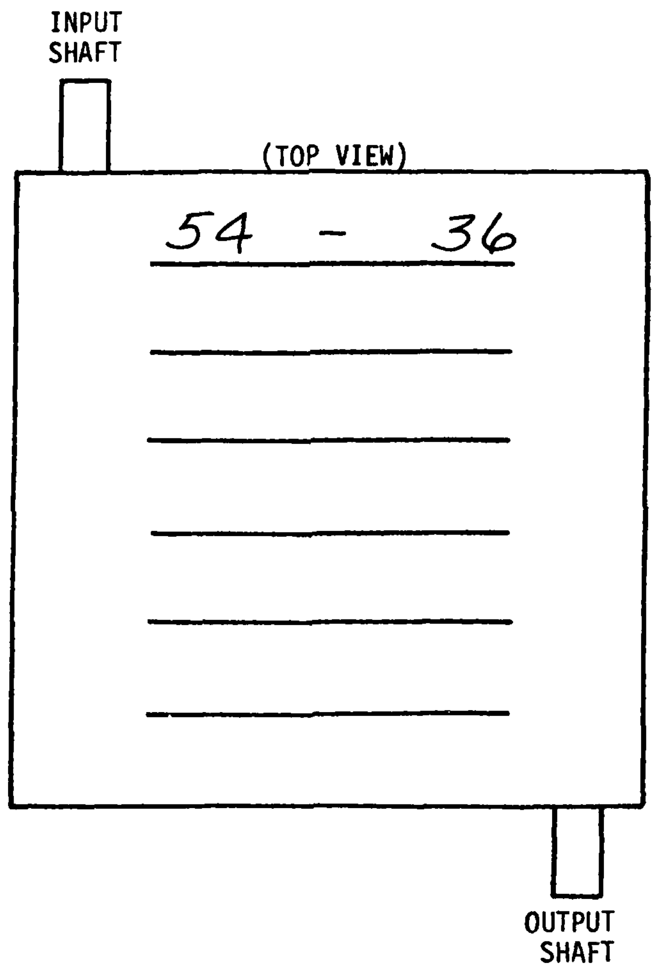
INCORRECT COUPLINGS NOTED

1. During the gear ratio tests it was noted that some of the flexible couplings were still the incorrect double-engagement type. Some of the double-engagement couplings had been welded in an attempt to modify them to a single-engagement type. A complete new set, to replace the welded and unmodified couplings, should be provided. The types are listed in table 6.



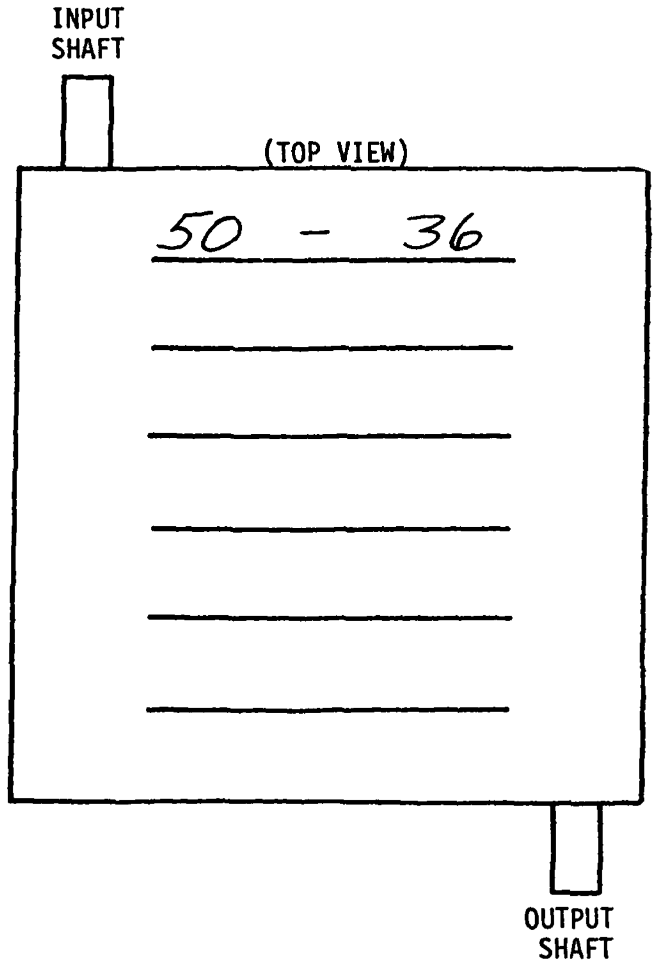
VARIOMETER GEAR BOX

Figure 1. Room 102, 10.20 kHz.



VARIOMETER GEAR BOX

Figure 2. Room 101, 11.05 kHz.



VARIOMETER GEAR BOX

Figure 3. Room 103, 11-1/3 kHz.

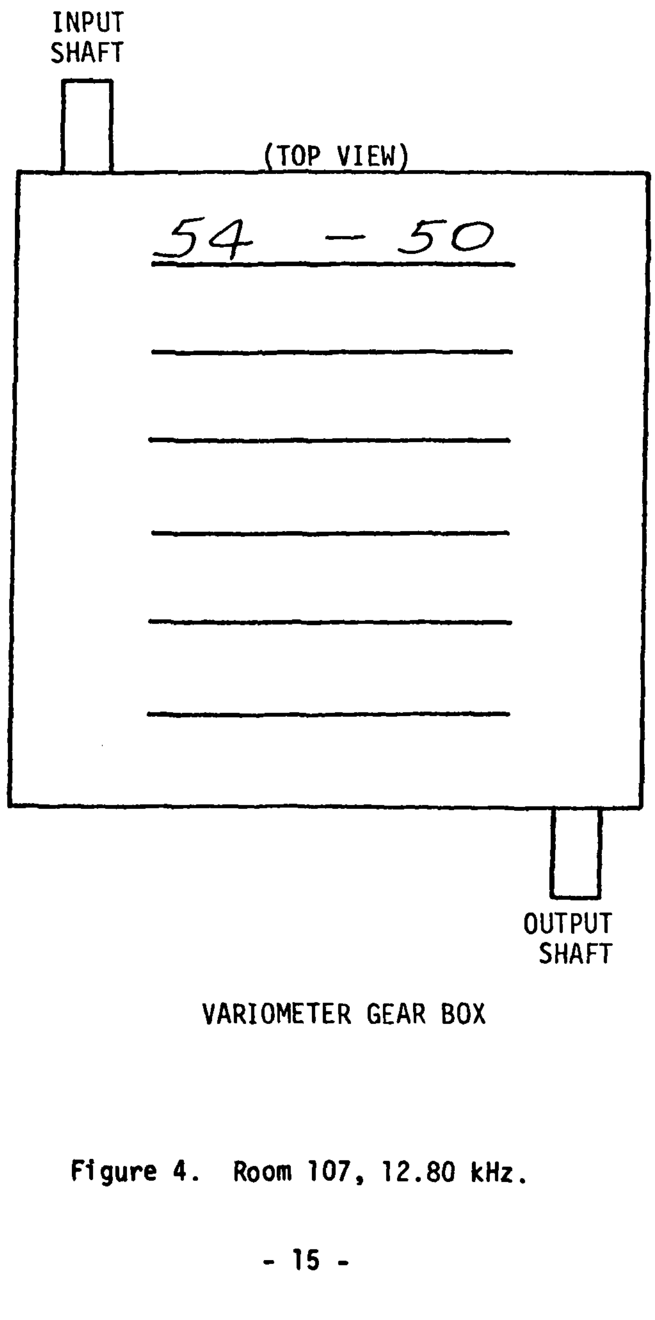
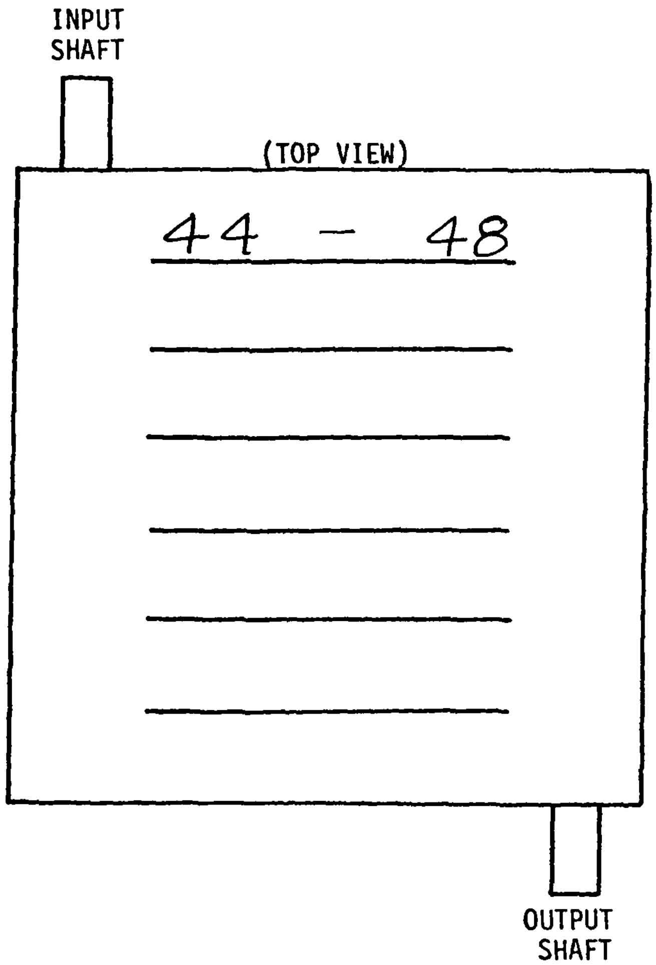


Figure 4. Room 107, 12.80 kHz.



VARIOMETER GEAR BOX

Figure 5. Room 108, 13.60 kHz.

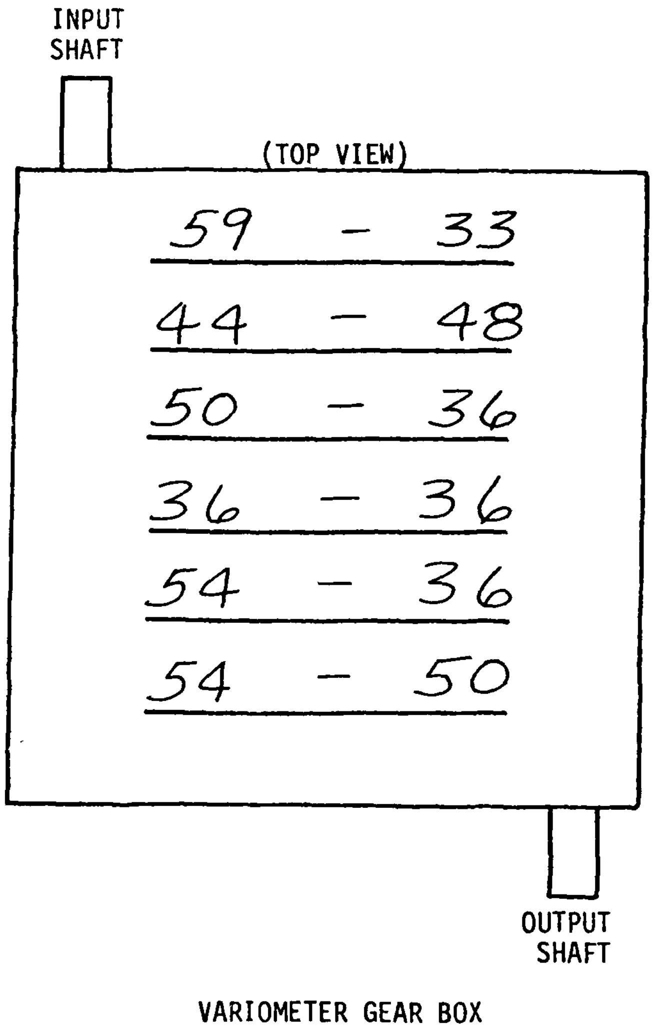


Figure 6. Room 106, spare.

TABLE 6. INVENTORY OF FLEXIBLE COUPLINGS.

Room	Gearbox to Variometer 15/16" to 1"	Variometer Room "T" Input 1" to 1"	Gear Box Output 1" to 1"
101	Double	Single (Welded)	None
102	Single	Single	Single
103	Double	Single	Single (Welded)
106	Double	Single	Single
107	Double	Single	Single (Welded)
108	Single	Single	None
Motor "T"		Single	Single

IV. FIELD INTENSITY MEASUREMENT

INTRODUCTION

1. To evaluate the performance of a station, the radiated power must be determined. It is determined by making field intensity measurements in as many clear areas and in as many radial directions as possible. Clear areas means the absence of structures such as power lines, fences, metal towers, buildings, pipelines, etc., capable of modifying the field intensity being measured. Since there are other factors, including unseen or buried structures, geological inhomogeneities, etc., that will modify the field intensity, a great many measurements are desirable. Statistical methods are used to obtain the average values and to provide a means of identifying obviously erroneous values. Measurements such as these, taken on the Earth's surface, require that the entire measurement area be reasonably flat and that the soil over which propagation takes place have rather high conductivity at the radio frequencies of interest.

2. Some of the OMEGA stations are located on sites which are almost impossible to measure on the ground. These are the mountainous coasts of Norway, the mountainous island of Tsushima, Japan and the volcanic islands of Hawaii and La Reunion. These areas, in addition to being almost impassable, are characterized by poor and variable ground conductivity. These conditions dictate measurement sites remote from the poorly conducting ground plane and above the impassable terrain. Some radial directions, at measurement distances, are over water. Surface (ship) measurements are

not feasible because of the elaborate calibration that would be required. Due to the low duty cycle pulses of the OMEGA signals, a moving vehicle (fixed wing aircraft) is a very unattractive platform. The length of time required to obtain an accurate measurement requires a stationary platform. Above the terrain, this means a helicopter.

3. The radiated field-distance product normalized by the antenna current ($E_r d/I_a$), leads directly to the electrical height and radiation resistance of the antenna (see Appendix B). This number is convenient to use in statistical manipulation.

POSITION DETERMINATION

1. The locations of the land based measurement sites and the station transmitting antenna were first plotted on a map (scale 1:25,000) then converted to metric grid coordinates. All maps used to locate these sites, and from which the metric grid coordinates are obtained, are from the U.S. Army Map Service, Series L872. The sheets are named and numbered. These are shown in table 7. The distances to the various land based sites are given in table 8.

2. The locations of all airborne measurements, both over land and over water, were determined by airborne ratio distance measuring equipment (DME) using the method of Appendix G. The position is given in terms of the azimuth, in degrees from true north (°T.), and distance, in kilometers, from the transmitting antenna. These values are recorded on Data Sheets 5 (DS-5) for each measurement. The distances only are transferred to Data Sheets 6 (DS-6) for use in the calculations thereon.

TABLE 7. LAND BASED SITE LOCATIONS.

1. Helicopter Calibration Site 1 (C1) (Map IZUMI, Sheet 3951 II SE)

Mean Map Scale : 1:24965

1 inch = 634.1 m.

Grid No.		Distance (Inches)		Grid Position
38-38-000	-	0.916	=	38-37-419 N
5-39-000	+	0.547	=	5-38-347 E

2. Helicopter Calibration Site 2 (C2) (Also Benchmark Site B2) (map NII, Sheet 3950 II SW)

Mean Map Scale : 1:25013

1 inch = 635.3 m.

Grid No.		Distance (inches)		Grid Position
38-04-000	+	0.070	=	38-04-044 N
5-28-000	+	0.498	=	5-28-316 E

TABLE 7. (cont)

3. Benchmark Site 1 (B1) (Map KECHI, Sheet 3949 I NE)

Mean Map Scale : 1:25055

1 inch = 636.4 m.

OMEGA Benchmark Site located 67.5 m. at 0.95^{o}T. from Surveyors Mark. This is: 6 m. S, 67 m. E.

Grid No.		Distance (Inches)		Grid Position
37-95-000	-	0.115	=	37-94-927
				- 6
				37-94-921 N
5-33-000	-	0.490	=	5-32-688
				+ 67
				5-32-755 E

TABLE 7 (cont)

4. Station Transmitting Antenna (Map SASUNA, Sheet 3950 I NE)

Mean Map Scale : 1:24968

1 inch = 634.2 m.

Grid No.		Distance (inches)		Grid Position
38-29-000	+	1.044	=	38-29-662 N
5-42-000	-	0.287	=	5-41-818 E

TABLE 8. DISTANCES FROM TRANSMITTING ANTENNA TO LAND BASED SITES.

A. Helicopter Calibration Site 1

Distance: 8141 m., 8.1 km.

Azimuth : 343^{o}T

B. Helicopter Calibration Site 2

Benchmark Site 2

Distance: 28958 m., 29.0 km.

Azimuth : 208^{o}T

C. Benchmark Site 1

Distance: 35904 m., 35.9 km.

Azimuth : 195^{o}T

3. DME transponder locations were chosen to provide proper crossing angles of the sides of the triangle being measured. The locations of the transponders are shown in table 9.

4. DME range data consisting of distances and azimuths between transponders, and from the transmitting antenna to the primary transponder, are shown in table 10.

ANTENNA CURRENT

1. Antenna current was maintained at a constant level during the calibration and measurement periods using procedure B of Appendix D, Revision 2.

2. It was necessary to reduce the normal antenna current to 150 amperes on each frequency in order to make measurements at calibration site C1. This was done to prevent limiting in the loop amplifier, LPA-1A, due to the proximity of the transmitting antenna which was only 8.1 Km distant.

3. Antenna current was maintained at 350 amperes during helicopter calibration at site C2 (also known as B2) and during measurements at the benchmark site B1.

4. During helicopter measurement flights the antenna current was dropped to 300 amperes because of an occasional arc at the higher value.

MEASUREMENTS

1. The helicopter was instrumented and calibrated at two sites, C1 and C2, following the procedures of Appendix E, Revision 1. These

TABLE 9. DME TRANSPONDER LOCATIONS.

A. Lighthouse, Primary (D1) (Map KIN, Sheet 3950 I SE)

Mean Map Scale : 1:24937

1 inch = 633.4 m.

Grid No.		Distance (inches)		Grid Position
38-22-000	+	1.078	=	38-22-683 N
5-43-000	+	0.217	=	5-43-137 E

B. Mountain Peak ME-DAKE, Primary (D1) (Map SHISHIMI, Sheet 3950 I SW)

Mean Map Scale: 1:25023

1 inch = 635.6 m.

Grid No.		Distance (inches)		Grid Position
38-25-000	+	0.470	=	38-25-299 N
5-35-000	+	0.790	=	5-35-502 E

TABLE 9. (cont)

C. Decca Station, Secondary (D2) (Map SAGO, Sheet 3950 I NW)

Mean Map Scale: 1:24992

1 inch = 634.8 m.

Grid No.		Distance (inches)		Grid Position
38-33-000	-	0.510	=	38-32-676 N
5-32-000	+	0.900	=	5-32-571 E

D. Loran Station, Secondary (D2) (Map SASUNA, Sheet 3950 I NE)

Mean Map Scale: 1:24968

1 inch = 634.2 m.

(Transponder moved 36 meters at 0.55^{o} from original position. +20.7 m. N, + 29.5 m. E)

Grid No.		Distance (inches)		Grid Position
38-35-000	-	0.056	=	38-34-964
			+	20.7
				38-34-985 N
5-44-000	+	0.206	=	5-44-131
			+	29.5
				5-44-161 E

TABLE 10. DME RANGE DATA FOR RADIAL POSITIONS.

Note: The mean difference between Grid North and True North is +0.25°.

A. Radial 1 (Clockwise Solution)
Radial 4 (Counterclockwise Solution)

Transponder Baseline		Position N	Position E
Secondary - Decca Station:		38-32-676	5-32-571
Primary - Lighthouse :		- 38-22-683	- 5-43-137
		+ 9993	- 10556
Distance :	1.454 305 350 EX 4		
Azimuth :	3.134 035 223 EX 2		
Grid N-True :	+ 2.5 EX-1		
True Azimuth:	3.136 535 223 EX 2		

Station to Primary Transponder		Position N	Position E
Lighthouse:		38-22-683	5-43-137
Station :		- 38-29-662	- 5-41-818
		- 6979	+ 1319
Distance :	7.102 548 979 EX 3		
Azimuth :	1.692 975 883 EX 2		
Grid N-True :	+ 2.5 EX-1		
True Azimuth:	1.695 475 883 EX 2		

TABLE 10. (cont)

B. Radials 2 and 3 (Clockwise Solution)

Transponder Baseline	Position N	Position E
Secondary - Loran Station:	38-34-985	5-44-161
Primary - Lighthouse :	- 38-22-683	- 5-43-137
	+ 12302	+ 1024

Distance :	1.234 454 454	EX 4
Azimuth :	4.758 245 446	EX 0
Grid N-True :	+ 2.5	EX-1
True Azimuth:	5.008 245 446	EX 0

Station to Primary Transponder	Position N	Position E
Lighthouse:	38-22-683	5-43-137
Station :	- 38-29-662	- 5-41-818
	- 6979	+ 1319

Distance :	7.102 548 979	EX 3
Azimuth :	1.692 975 883	EX 2
Grid N-True :	+ 2.5	EX-1
True Azimuth:	1.695 474 883	EX 2

TABLE 10. (cont)

C. Radial 6 (Counterclockwise Solution)

Transponder Baseline		Position N	Position E
Secondary - Decca Station :		38-32-676	5-32-571
Primary - Mountain ME-DAKE:		- 38-25-299	- 5-35-502
		+ 7377	- 2931
Distance :	7.937 939 909 EX 3		
Azimuth :	3.383 312 846 EX 2		
Grid N-True :	+ 2.5 EX-1		
True Azimuth:	3.385 812 846 EX 2		

Station to Primary Transponder		Position N	Position E
Mountain ME-DAKE:		38-25-299	5-35-502
Station :		- 38-29-662	- 5-41-818
		- 4363	- 6316
Distance :	7.676 433 091 EX 3		
Azimuth :	2.353 638 534 EX 2		
Grid N-True :	+ 2.5 EX-1		
True Azimuth:	2.356 138 534 EX 2		

NOTES: 1. Baselines and azimuths given to 10 significant figures only to minimize computational errors.

2. The notation "EX (N)" means the power of 10. It is presented in this manner to facilitate keyboard entry on the calculator used.

measurements are recorded on Data Sheets DS-5 and summarized in tables 11 and 12. The calculation of the vehicle factor, K_3, is shown in table 13. The ground based measurements taken at C2 were transcribed to benchmark data sheets DS-5 and DS-6. No data sheet DS-6 was prepared for site C1 because the proximity of the transmitting antenna made the data unreliable.

2. A height-gain test was performed over Site C2. The site seemed to be typical of the two radials that would be flown predominantly over land. A measurement was taken of each frequency at altitudes of 500, 1000, 1500, and 2000 feet above sea level. No DME was deployed during this flight so position fixing was done visually. A plot of the effective height (h_e) of the antenna for each frequency and at each level of flight is given as figure 7. Even though the distance was not being precisely measured, the differences of effective heights with changing altitudes are remarkably small. The dashed lines are the mean at the surface and the mean at altitude.

3. Field intensity measurement flights were made at 1000 feet altitude over water. Over land flights were made at 2000 and 2500 feet altitudes to obtain approximately 1000 feet of terrain clearance and to obtain line of sight operation for the DME transponders; not because of any implied height gain factor.

4. All airborne FIM were made in accordance with Appendix E. Dye markers bombs were dropped into the water, to provide a hover reference, after confirmed arrival in the measurement area. All data taken were recorded on Data Sheets 5 (DS-5). After calculation of positions, using the method of Appendix G, each was recorded in the appropriate column. Note that a position fix was obtained for each reading taken.

TABLE 11. SUMMARY, HELICOPTER CALIBRATION, SITE C1.

Station to C1: Azimuth 343°T., Distance 8.1 Km.

Frequency (kHz)	Tripod (E_g x 0.99)	E_g (Mean) Helo Toward	K_3 Ratio	Helo Away	K_3 Ratio
10.20	59.9	56.3	1.064	55.7	1.075
11.05	62.9	59.3	1.061	59.1	1.064
11-1/3	63.4	59.8	1.060	59.5	1.066
12.80	73.4	68.8	1.067	69.0	1.064
13.60	79.6	75.3	1.057	74.5	1.068
		K_3 Mean (Toward)	1.062	(Away)	1.067

TABLE 12. SUMMARY, HELICOPTER CALIBRATION, SITE C2.

Station to C2: Azimuth 208^{o}T., Distance 29.0 Km.

Frequency (kHz)	Tripod (E_g x 0.99)	Eg (Mean) Helo Toward	K_3 Ratio	Helo Away	K_3 Ratio
10.20	29.0	27.1	1.070	27.3	1.062
11.05	31.1	28.9	1.076	29.0	1.072
11-1/3	31.8	29.6	1.074	29.6	1.074
12.80	37.0	34.5	1.072	34.6	1.069
13.60	39.2	36.5	1.074	36.5	1.074
		K_3 Mean (Toward)	1.073	(Away)	1.070

Table 13. SUMMARY, HELICOPTER CALIBRATION.

Site	Loop Toward	Loop Away
C1	1.062	1.067
C2	1.073	1.070
Mean	1.07	1.07

Therefore K_3 is non-directional.

$K_3 = 1.07$

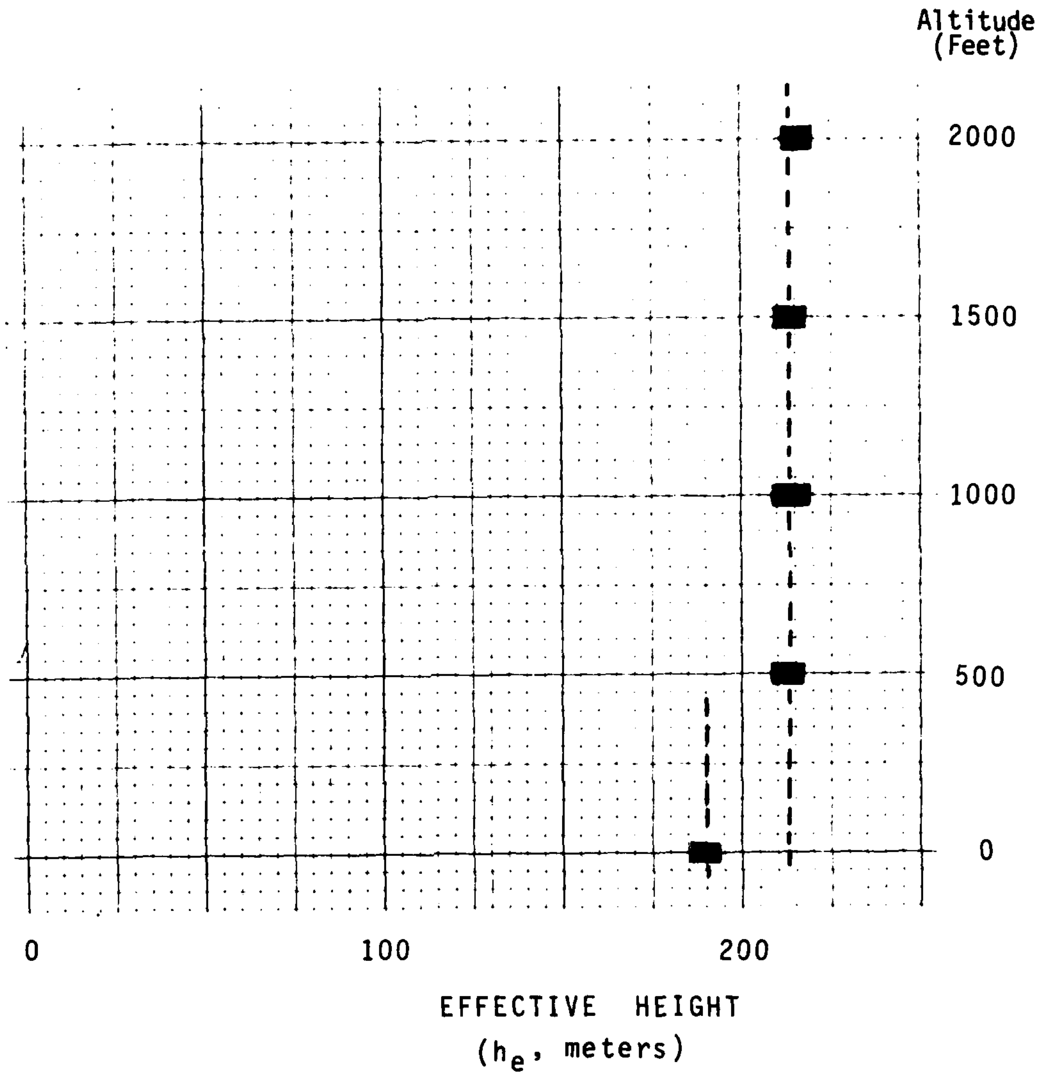


Figure 7. Height-gain, site C2.

5. Figure 8 shows the radial directions and distance circles. The intersections are locations over which airborne measurements were made.

6. The heading information required to complete the Data Sheet DS-6 was transcribed from DS-5. Each measurement consisting of E_g and distance was transcribed from DS-5 to DS-6.

7. Calculations required to complete each of DS-6 were made using equations from Appendix B.

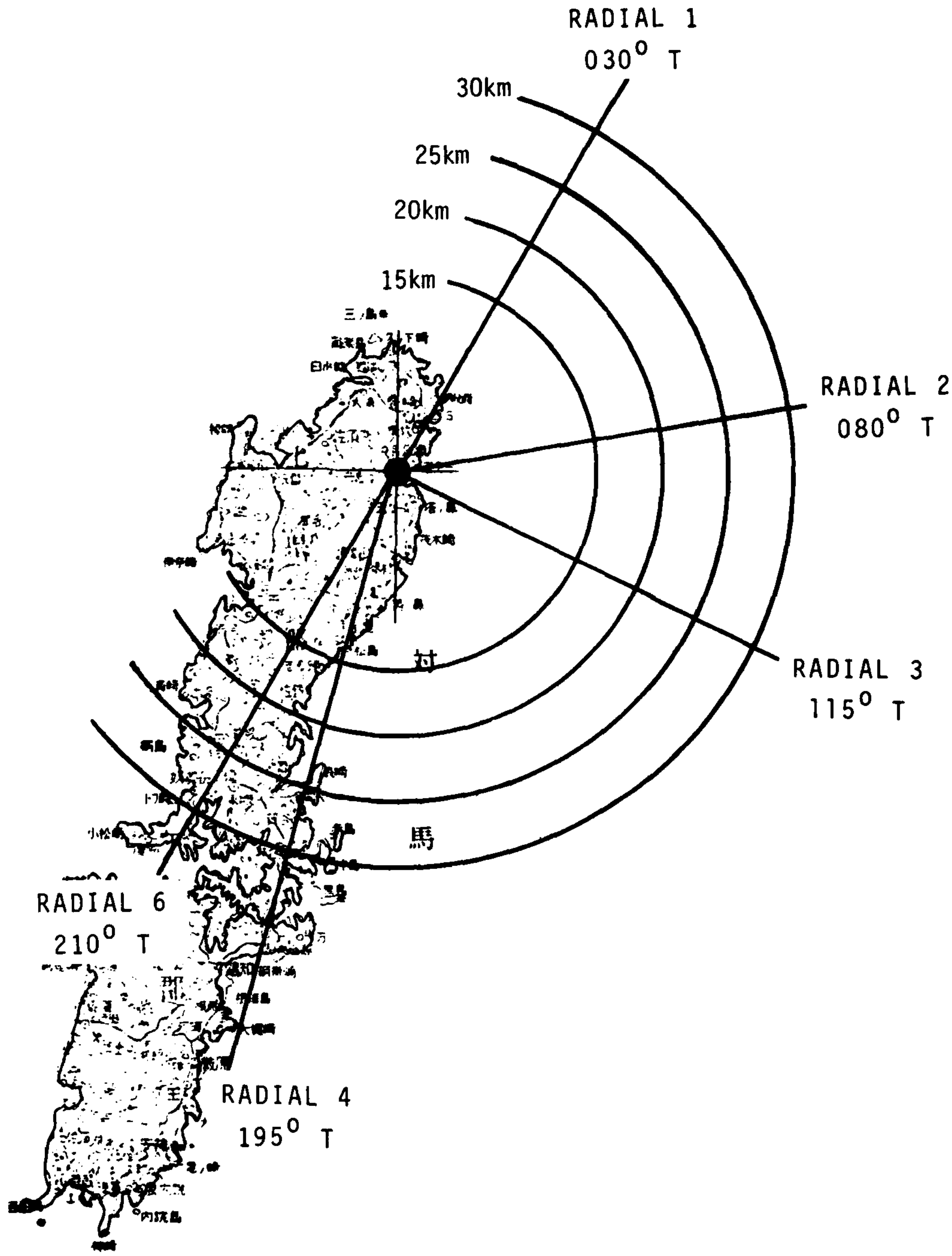


Figure 8. Tsushima Japan.

V. SUMMARY

FIELD INTENSITY MEASUREMENTS

1. Mean values of the normalized field-distance products, effective heights, radiation resistances and antenna currents required for a radiated power of 10 kilowatts are shown, for each frequency, in tables 14 through 18. These values are tabulated by each radial direction measured. A mean value of all measurements is also given.

2. Examination of tables 14 through 18 shows no clear indication of a pattern other than circular. All of the measurements were taken at directions other than west due to the proximity of Korea.

OTHER ANTENNA SYSTEM MEASUREMENTS

1. No antenna system resistance measurements were made by the author, however Japanese engineers did make a set of measurements.

2. The value seemed to be abnormally high. Since no more down time was available additional measurements were not possible. Instead, a substitution type estimate was done. The procedure is to run the transmitter into the dummy load at full power carefully noting all panel meter indications; then changing the transmitter to the antenna load. If all the meter readings are duplicated at the same drive level the actual load is the same as the nameplate data of the output transformer.

TABLE 14. FIM SUMMARY AND OPERATING PARAMETERS, 10.20 kHz.

Radial	Number of Measurements	$E_r d/I_a$	h_e m	h_e ft	R_r (ohms)	Pr = 10 KW I_a (A.)	Pr = 10 KW I_{as} (A.)
1	12	2.714	212	695	0.0818	350	357
2	12	2.714	212	695	0.0818	350	357
3	12	2.701	211	691	0.0811	351	358
4	12	2.677	209	685	0.0796	354	362
6	12	2.649	207	678	0.0780	358	365
Mean	60	2.691	210	689	0.0805	353	360

TABLE 15. FIM SUMMARY AND OPERATING PARAMETERS, 11.05 kHz.

Radial	Number of Measurements	$E_r d/I_a$	h_e m	ft	R_r (ohms)	Pr = 10 KW I_a (A.)	I_{as} (A.)
1	12	2.933	211	693	0.0956	323	330
2	12	2.910	210	688	0.0941	326	333
3	12	2.922	210	690	0.0949	325	331
4	12	2.918	210	689	0.0946	325	332
6	12	2.822	203	667	0.0885	336	343
Mean	60	2.901	209	685	0.0935	327	334

TABLE 16. FIM SUMMARY AND OPERATING PARAMETERS, 11-1/3 kHz.

Radial	Number of Measurements	$E_r d/I_a$	h_e m	h_e ft	R_r (ohms)	Pr = 10 KW I_a (A.)	Pr = 10 KW I_{as} (A.)
1	12	2.999	211	691	0.0999	316	323
2	12	2.981	209	687	0.0987	318	325
3	12	2.999	211	691	0.0999	316	323
4	12	2.993	210	690	0.0995	317	323
6	12	2.922	205	673	0.0949	325	331
Mean	60	2.979	209	686	0.0986	318	325

TABLE 17. FIM SUMMARY AND OPERATING PARAMETERS, 12.80 kHz.

Radial	Number of Measurements	$E_r d/I_a$	h_e m	h_e ft	R_r (ohms)	Pr = 10 KW I_a (A.)	I_{as} (A.)
1	12	3.428	213	699	0.1306	277	282
2	12	3.412	212	696	0.1294	278	284
3	12	3.396	211	693	0.1281	279	285
4	12	3.392	211	692	0.1278	280	285
6	12	3.331	207	679	0.1233	285	291
Mean	60	3.393	211	692	0.1279	280	285

TABLE 18. FIM SUMMARY AND OPERATING PARAMETERS, 13.60 kHz.

Radial	Number of Measurements	$E_r d/I_a$	h_e m	h_e ft	R_r (ohms)	Pr = 10 KW I_a (A.)	Pr = 10 KW I_{as} (A.)
1	12	3.644	213	700	0.1475	260	266
2	12	3.604	211	692	0.1443	263	269
3	12	3.622	212	695	0.1458	262	267
4	12	3.592	210	690	0.1434	264	270
6	12	3.539	207	679	0.1392	268	274
Mean	60	3.599	211	691	0.1439	264	269

3. During this test no appreciable change could be detected from the values originally measured in 1974. No change was made in the tap ratio.

VI. BENCHMARKS

INTRODUCTION

1. To make field intensity measurements in the future, for determination of the condition of the transmitting antenna or changes in it, it is required that one or more benchmark sites be chosen for these measurements. For meaningful comparison, of data taken in the future, the local environment of the site must not change.

2. The benchmark sites should be far enough from the transmitting antenna that the correction for induction field is small, and near enough to have a good signal-to-noise ratio. The distances between 15 and 40 kilometers satisfy these requirements.

SITE SELECTION

1. The usual procedure is to select a site, or sites, under control of the operating agency. Sites on land to the north and west were too close, and the Sea of Japan was to the east, leaving only the area generally to the south.

2. Within the above constraints was the OMEGA Monitor Site, however, there is much other electronic activity there. The null of the loop antenna was poor and the noise level very high.

3. Two sites were finally selected which seemed likely to remain unchanged. Site B1 was on top of a hill at a national scenic viewpoint and

the other, Site B2, the center of an active heliport which was also used for vehicle calibration. Site B1 had no nearby power lines but power lines passed two to three hundred meters from Site B2. The approximate locations are shown in figure 9. The precise locations of these sites are given in table 7. Maritime Safety Agency personnel indicated that they would mark Site B1. Site B2 does not need identification.

MEASUREMENTS

1. Field intensity measurements were conducted at each of the two benchmark sites using the method of Appendix C while the antenna current was being controlled using the method of Appendix D, Procedure B. Note that the tripod measurements made for helicopter calibration at Site 2 are the benchmark measurements for Site B2. Data Sheets DS-5 and DS-6 were completed to obtain the mean values of the normalized field-distance product, $E_r d/I_a$. These values when compared to the mean values of the airborne measurements produce the site calibration factor or ratio. Summaries and the mean site calibration factors are shown in tables 19 and 20.

2. In practice the site calibration factor may be used for K_3, of equation 2 Appendix B and Data Sheet DS-6, when measurements are made on a tripod.

CALCULATIONS

1. In the future, after new measurements have been processed, using Data Sheets DS-5 and DS-6, new operational parameters may be calculated and implemented if necessary.

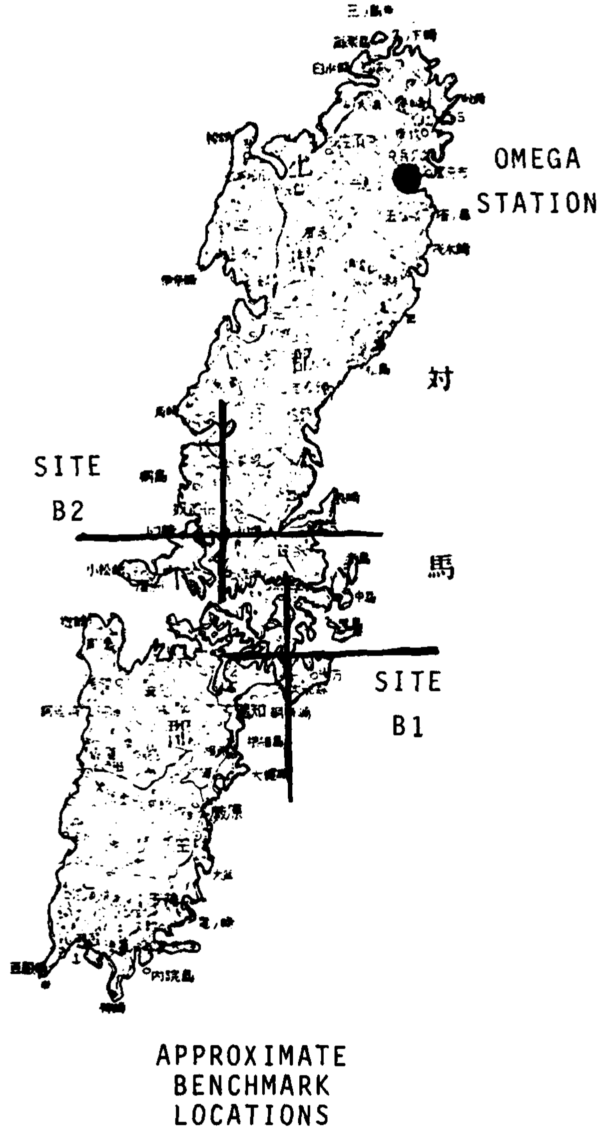


Figure 9. Tsushima, Japan.

TABLE 19. BENCHMARK SUMMARY, SITE B1.

Site B1 (Table 7, paragraph 3 and Figure 9)

Frequency (kHz)	$E_r d/I_a$ Mean Airborne	$E_r d/I_a$ Mean Surface	Ratio Air/Surface
10.20	2.691	3.103	0.867
11.05	2.091	3.247	0.893
11-1/3	2.979	3.279	0.909
12.80	3.393	3.769	0.900
13.60	3.599	3.932	0.915
		Mean Site Calibration Factor:	0.897
		Standard Deviation:	0.019

TABLE 20. BENCHMARK SUMMARY, SITE B2.

Site B2 (Table 7, paragraph 2 and Figure 9)

Frequency (kHz)	$E_r d/I_a$ Mean Airborne	Mean Surface	Ratio Air/Surface
10.20	2.691	2.424	1.110
11.05	2.901	2.600	1.116
11-1/3	2.979	2.665	1.118
12.80	3.393	3.102	1.094
13.60	3.599	3.291	1.094
		Mean Site Calibration Factor:	1.106
		Standard Deviation:	0.012

APPENDIX A. ABBREVIATIONS AND ACRONYMS

A	Amperes
Az	Azimuth angle, transmitter to measurement site
BIA	Base insulator assembly
C	Capacitance
ΔC	Capacitance change
C_{app}	Apparent capacitance (antenna)
cm	Centimeter
COGARD	Coast Guard
D	Distance (a readout)
d	Distance (km)
DME	Distance measuring equipment
DMU	Distance measuring unit
DSRC	Drive shaft revolution counter
E	Potential (volts)
E_g	Output voltage, signal generator (mV)
E_m	Field intensity, corrected for instrumentation (mV/m) (loop and vehicle factors)
E_r	Radiation field intensity, corrected to remove induction field (mV/m)
f	Frequency
FDP	Field distance product per ampere
h_e	Effective height (metres)
Hz	Hertz
I	Current (Amperes)
I_a	Current, antenna, corrected for losses in Helix House

I_{as}	Current, antenna system
in.	Inch
K_1	Ratio of I_a/I_{as}
K_2	Loop injection correction factor (1090/R)
K_3	Vehicle correction factor
kHz	Kilohertz
km	Kilometer
L	Inductance
ΔL	Induction change
L_H	Inductance of helix (mH)
L_T	Inductance required to resonate C_{app} at f (mH)
L_V	Inductance of variometer at position indicated (mH) (-cm = distance inner coil is down from the top)
m	Metre
mV	Millivolts
N	Number (of turns in an inductor)
OMSTA	OMEGA station
ONSOD	OMEGA navigation systems operations detail
P_r	Radiated power (kW)
P_v	Variometer position, cm down from the top
R_{as}	Antenna system resistance
R_r	Radiation resistance (ohms)
STA	Station (antenna)
S_x	Standard deviation
TR	Transponder
$\bar{x}$	Mean
ηas	Antenna system efficiency

APPENDIX B: EQUATIONS

1. Antenna Current

$$I_a = I_{as}K_1$$

2. Measured Field

$$E_m = E_g K_2 K_3$$

3. Radiation Field*

$$E_r = \frac{Em}{\left[1 + \left(\frac{300}{2\pi fd}\right)^2\right]^{1/2}}$$

4. Radiated Power

$$P_r = \left(\frac{E_r d}{300}\right)^2$$

5. Effective Height

$$h_e = \frac{10^4 E_r d}{4\pi I_a f}$$

6. Radiation Resistance

$$R_r = \frac{P_r \times 10^3}{I_a^2} \text{ or } \frac{1}{90}\left(\frac{E_r d}{I_a}\right)^2$$

7. Field Distance Product, Normalized

$$FDP = \frac{E_r d}{I_a}$$

*It is noted that this expression for correcting total field to radiated field applies for magnetic field type measurements, such as were performed in this work using a loop antenna. Although the results are given to E, electric field, strictly speaking H, magnetic field, was actually measured. The complete correction for E involves a 3rd term, not shown here.

8. Distance, Great Circle, Nautical Miles

$$d = 60 \cos^{-1} [\sin L_1 \sin L_2 + \cos L_1 \cos L_2 \cos (\lambda_2 - \lambda_1)]$$

(nautical miles X 1.83 = kilometres)

*(HEWLETT-PACKARD NAVIGATION PAC 1, NAV 1-10A)

9. Azimuth, Initial

$$A_z = \cos^{-1} \left[\frac{\sin L_2 - \sin L_1 \cos (d/60)}{\sin (d/60) \cos L_1} \right]$$

*(HEWLETT-PACKARD NAVIGATION PAC 1, NAV 1-10A)

10. Mean

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

*(HEWLETT-PACKARD STANDARD PAC, STD 02A)

11. Standard Deviation

$$S_x = \sqrt{\frac{\sum_{i=1}^{n} x_i^2 - n\bar{x}^2}{n-1}}$$

*(HEWLETT-PACKARD STANDARD PAC, STD 02A)

*Equations 8, 9, 10, and 11 are all taken from the appropriate programs for the HP-65 calculator, which was used to prepare this report.

APPENDIX C: FIELD INTENSITY MEASUREMENTS, SUBSTITUTION METHOD

(Revision 1)

1. INTRODUCTION

This kind of Field Intensity Measurement is made feasible because of a method of calibrating field strength measuring equipment developed by Dinger and Garner of Naval Research Laboratory. This technique is described and justified in their NRL Memorandum Report 83, "A New Method of Calibrating Field Strength Measuring Equipment," dated 14 November 1952. Basically this method consists of injection of a constant current (high resistance source) into the loop shield which is considered to be unity coupled to the winding of the loop. A loop antenna, modified in accordance with illustrations given in this report, is employed. (See figure C1.) The signal path, for both the received signal and the calibrating signal, occupies common equipment eliminating the requirement of known gain from the antenna to the indicator. Only the value of a resistor in the loop modification and the accuracy of the voltmeter are required to establish the precision of the measurement. It is possible to determine both of these by independent means.

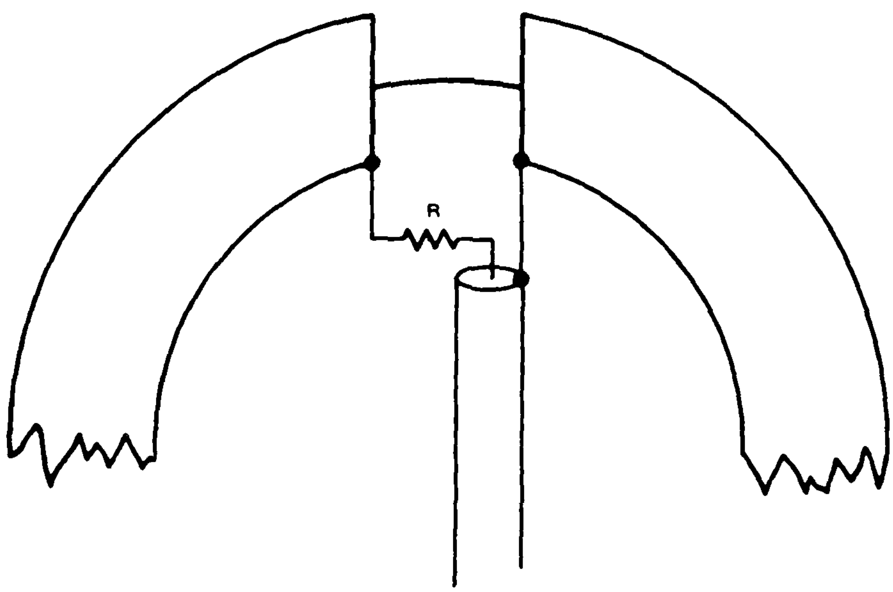


Figure C1

II. PROCEDURE

A. In Section B a step-by-step procedure for taking a measurement will be given. This procedure must be tempered by a certain amount of judgement based on experience. Experience is best gained by making a large number of measurements. However, some guidelines may be helpful:

1. Visual observation of fences, pipes, structures, power lines (especially those which could directly carry a signal from the transmitter to the measurement site) and the location of your own vehicle could show that a site is less than desirable.

2. One of the tests of a site is to orient the loop for a null (minimum signal on the indicator). The following two features of the null may indicate that a site is undesirable:

a. The minimum signal level of the null is greater than 1% of the maximum signal.

b. The direction of the null (right angle to the plane of the loop) is more than five (5) degrees from the direction to the transmitting antenna.

3. Compare the measured field strength with the expected field strength based on the design goals of the antenna. If there is a radical difference try other measurement sites nearby, correcting for any change in distance to the transmitting antenna. A large difference could be caused by invisible (possibly buried) conductors such as pipes or wires.

B. Select a site using the visual criteria of Section A.1.

1. Set up the loop antenna approximately 15 metres from the other measuring equipment in such a location that the direction to the transmitting antenna and the direction to the measuring equipment differ by approximately 90 degrees. (See figure C2).

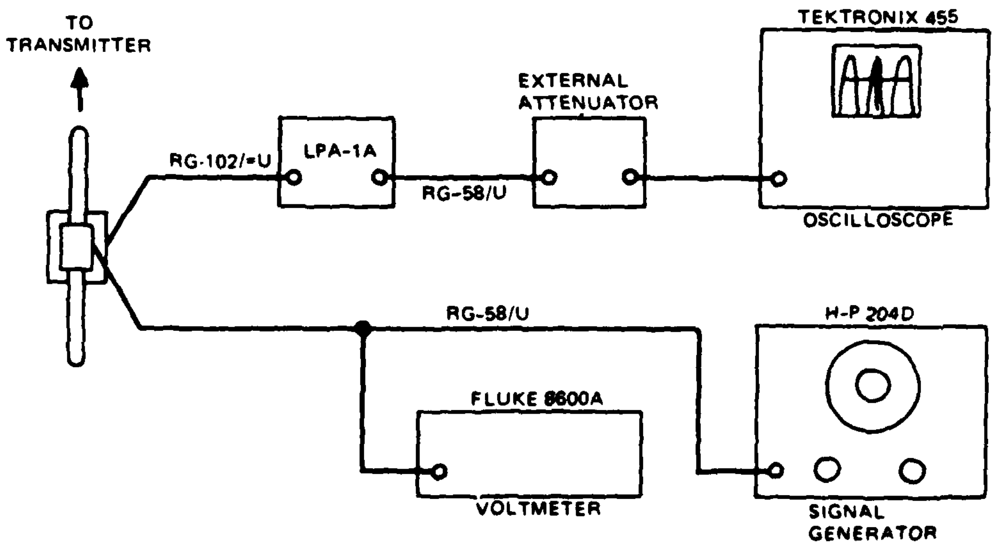


Figure C2

2. Set the Frequency Selector Switch, of the LPA-1A, to the frequency having the highest duty cycle. If f_t is being transmitted on four segments it would be used. If not, use the frequency on the segment having the longest duration.

3. Attach the LPA-1A external attenuator to the CH2 input jack of the Tektronix 455 Oscilloscope. Adjust the external attenuator to minimum loss (CW).

4. Set the controls of the oscilloscope as follows:

   a. Power Switch: DC, ON

   b. Horizontal Display: A

   c. Trigger Mode: AUTO

   d. Coupling Source: AC, Normal

   e. A Trigger Level: 0

   f. A and B Time/Div: 0.2 ms, Calibrated

   g. Intensity, Focus, Horizontal and Vertical Position: As necessary to center the display on the screen.

   h. Vertical Channel Selector: CH2

   i. Vertical Coupling Switch: AC

5. With the plane of the loop aimed at the transmitting antenna, set the oscilloscope vertical gain control to the Calibrated position and the vertical attenuator to produce an "on screen" waveform.

6. Calculate the attenuator setting and waveform size if the normal voltage was reduced to 1%. Set the vertical attenuator to this value.

7. Turn the loop approximately 90 degrees either direction then adjust the loop position for minimum signal (null) as indicated on the oscilloscope.

8. If the amplitude of the signal, at the null, is $\leqslant 1\%$ of step 5 check the bearing of the null (90 degrees to the plane of the loop). If the bearing of the null is within ±5 degrees of the direction to the transmitting antenna and the amplitude is $\leqslant 1\%$ the site is probably acceptable. If the site fails this test, move a few hundred metres, preferably at a constant distance to the station, and remeasure. Statistical tests, after all data are taken, may indicate anomalies not detected above.

9. If satisfied with the site, turn the plane of the loop toward the transmitting antenna to obtain the maximum signal.

10. Set the controls of the Textronix 455 Oscilloscope as follows:

   a. Vertical Position: Full CCW (down)

   b. Vertical Attenuator: 10 mV/div, calibrated, AC

   c. A and B Time/Div: 20 μs, calibrated

   d. Adjust the LPA-1A External Attenuator control so the tips of the waveform are between 6 and 8 cm high.

   e. Adjust the horizontal position so one of the waveform tips is over the vertical centerline of the screen.

11. Turn the signal generator ON. Adjust the output of the generator to the exact frequency of the Omega signal selected by the loop amplifier (zero beat frequency).

12. Remove the signal generator output in the manner shown below:

a. If using a Hewlett-Packard 204D oscillator as a signal generator move the Range Selector switch to X 1K during periods of time that the generator voltage is unneeded. Do not switch OFF.

b. If using a special oscillator as a signal generator switch the frequency control to an intermediate step or switch the carrier OFF if a switch is available.

13. Observe the tip of the waveform in the center for 2 or 3 successive pulses, noting the vertical position.

14. Turn the loop antenna to the null position. (If it is impractical to turn the antenna to the null position, such as is the case in a helicopter, the next step may be accomplished during the 200 ms spaces between transmissions.)

15. Return the signal generator output, that was removed in step 11, to the selected frequency. Adjust the signal generator output control to produce a waveform identical in amplitude to the one noted in step 12.

16. Read the digital voltmeter to obtain the value of the signal generator output. Enter this value on Data Sheet 5.

17. Switch the LPA-1A to each frequency being measured, repeating steps 9 through 15 for each frequency.

18. Transcribe the necessary information from Data Sheets 3, 4, and 5 to the appropriate spaces on Data Sheet 6. Perform the required calculations to complete Data Sheet 6.

Note: One or more Data Sheets may be required to calculate the distance from the transmitting antenna to the measurement site.

DATA SHEET 4-A

RADIO FIELD INTENSITY

SITE LOCATION

BENCHMARK & CALIBRATION

OMEGA STATION, ________________ DATE: ____________

SITE NUMBER: ________

1. LOCATION OF MEASUREMENT:

   Description: ____

2. GEOGRAPHIC COORDINATES: (Map or Chart Scale. 1: ______________)

   ____° ____' ____" ( ) ____ . ________ = Lat. ____ . ________° ( )
   (DD) (MM) (SS) (Inches) (DD) (dd)
   Nearest Lat. Line ± Dist. to position N or S

   ________ . ________ ( ) ____ . ________ = ________ . ______ ( )
   Nearest Metric Grid (MM) (m)

   ____° ____' ____" ( ) ____ . ________ = Long. ____ . ________° ( )
   (DDD) (MM) (SS) (Inches) (DDD) (dd)
   Nearest Long. Line ± Dist. to Position E or W

   ________ . ________ ( ) ____ . ________ = ________ . ______ ( )
   Nearest Metric Grid (MM) (m)

3. LOCATION OF TRANSMITTING ANTENNA:

   Description, if other than tower.

   Lat. ____ . ________° ( )
   (DD) (dd)
   N or S

   Metric Grid ________ . ______ ( )
   (MM) (m)

   Long. ____ . ________° ( )
   (DDD) (dd)
   E or W

   Metric Grid ________ . ______ ( )
   (MM) (m)

   ____
   ____
   ____
   ____
   ____

4. SIGNAL PATH; TRANSMITTER TO RECEIVER SITE: Azimuth: ________ °T. Distance: ________ km.

DATA SHEET 4-B

RADIO FIELD INTENSITY

SITE LOCATION

D M E BASELINE

OMEGA STATION, ____________ DATE: ____________

RADIAL NUMBER: ________

1. LOCATION OF TRANSPONDERS.

No. 1 (Map or Chart Scale. 1:________)

___° ___' ___" (DD) (MM) (SS) Nearest Lat. Line	( )	___.___ (Inches) ± Dist. to position	=	Lat. ___ . ___° (DD) (dd)	( ) N or S
___.___ Nearest Metric Grid	( )	___.___	=	___ . ___ (MM) (m)	( )
___° ___' ___" (DDD) (MM) (SS) Nearest Long. Line	( )	___.___ (Inches) ± Dist. to Position	=	Long. ___ . ___° (DDD) (dd)	( ) E or W
___.___ Nearest Metric Grid	( )	___.___	=	___ . ___ (MM) (m)	( )

No. 2 (Map or Chart Scale. 1:________)

___° ___' ___" (DD) (MM) (SS) Nearest Lat. Line	( )	___.___ (Inches) ± Dist. to Position	=	Lat. ___ . ___° (DD) (dd)	( ) N or S
___.___ Nearest Metric Grid	( )	___.___	=	___ . ___ (MM) (m)	( )
___° ___' ___" (DDD) (MM) (SS) Nearest Long. Line	( )	___.___ (Inches) ± Dist. to Position	=	Long. ___ . ___° (DDD) (dd)	( ) E or W
___.___ Nearest Metric Grid	( )	___.___	=	___ . ___ (MM) (m)	( )

2. TRANSPONDER BASELINE, 1 TO 2.

Azimuth: ___ . ________ °T.

Distance: ___ . ________ km.

DATA SHEET 4-C

RADIO FIELD INTENSITY

SITE LOCATION

ANTENNA TO TRANSPONDER BASELINE

OMEGA STATION, ____________________ DATE: ____________

RADIAL NUMBER: ________

1. LOCATION OF TRANSMITTING ANTENNA. (Map or Chart Scale. (1:__________)

____ ° . ____ ' ____ " ( ) ____ . ________ = Lat. ____ . ________ ° ( )
(DD) (MM) (SS) (Inches) (DD) (dd)
Nearest Lat. Line ± Dist. to Position N or S

____________ . ____ ( ) ____ . ________ = ____________ . ____ ( )
Nearest Metric Grid (MM) (m)

____ ° . ____ ' ____ " ( ) ____ . ________ = Long. ____ . ________ ° ( )
(DDD) (MM) (SS) (Inches) (DDD) (dd)
Nearest Long. Line ± Dist. to Position E or W

____________ . ____ ( ) ____ . ________ = ____________ . ____ ( )
Nearest Metric Grid (MM) (m)

2. LOCATION OF TRANSPONDER 1
(From DS-4-B)

Lat. ____ . ________ ° ( )
(DD) (dd)
N or S

Metric Grid ____________ . ____ ( )
(MM) (m)

Long. ____ . ________ ° ( )
(DDD) (dd)
E or W

Metric Grid ____________ . ____ ( )
(MM) (m)

3. TRANSMITTING ANTENNA TO TRANSPONDER 1.

Azimuth: ____ . ________ °T.

Distance: ____ . ________ km.

DATA SHEET 4-D

RADIO FIELD INTENSITY

SITE LOCATION

MEASURED BY D M E

OMEGA STATION, ____________________ DATE: ____________

1. LOCATION OF MEASUREMENT SITE NUMBER: ____________

   Description: ____

2. TRANSPONDER 1 to 2 BASELINE: Azimuth _____ . ________________ ^{o}T.

   Distance _____ . ________________ km.

3. ANTENNA TO TRANSPONDER 1: Azimuth _____ . ________________ ^{o}T.

   Distance _____ . ________________ km.

4. DMU READINGS: D_1 __________ km, D_2 __________ km.

5. CALCULATED POSITION OF VEHICLE, ANTENNA TO VEHICLE.

   Distance _____ . _____ km.

   Azimuth _____ . _____ ^{o}T.

DATA SHEET 5 (DS-5)

RADIO FIELD INTENSITY MEASUREMENTS

OMEGA STATION:______________ SITE NO._____ DATE:_________________________

I_{as}________ A. K_1 ____ . _____ K_2 ____ . _____ K_3 ____ . ____

LOOP HEIGHT ____________ (m./ft.) TRIPOD ______ HELICOPTER _______
(ABOVE: SURFACE - SEA LEVEL)

TYPE OF MEASUREMENT: HELICOPTER CAL. ___ BENCHMARK ___ ROUTINE ___

TIME (LOCAL)	FREQUENCY (kHz)	E_g (mV)	HEADING (Mag.)	DME D1	DME D2	DIST. km.	AZ. °T.
	10.20						
	13.60						
	11.1/3						
	11.05						
	F_t						

	10.20						
	13.60						
	11-1/3						
	11.05						
	F_t						

	10.20						
	13.60						
	11-1/3						
	11.05						
	F_t						

COMMENT

DATA SHEET 6 (DS-6), REV 1

RADIO FIELD INTENSITY CALCULATIONS

HELICOPTER CAL. ______. BENCHMARK ______ ROUTINE ______

LOOP HEIGHT ______ (m./ft.) TRIPOD ______ HELICOPTER ______

(Above Surface/S.L.)

OMEGA STATION: ______________ SITE NUMBER: ______________ DATE: ______________

Distance: ______ . ____ km., K_1 = $\frac{\quad}{I_a/I_{as}}$ K_2 = $\frac{\quad}{\text{Loop Factor}}$ K_3 = $\frac{\quad}{\text{Vehicle Factor}}$

(If constant)

Dist. (km.)	Freq. (kHz)	I_{as} (A)	E_g (mV)	I_a (A)	E_m (mV/m)	E_r (mV/m)	P_r (kW)	h_e (m)	R_r (Ohm)	E_rd/I_a (Units)
.	10.20									
.										
.										
.	13.60									
.										
.										
.	11-1/3									
.										
.										
.	11.05									
.										
.										
.										
.										
.										
.										
.										

APPENDIX D: ANTENNA CURRENT MEASUREMENTS, SUBSTITUTION METHOD

(Revision 2)

I. INTRODUCTION

1. The Omega transmission consists of a series of pulses whose lengths are between 900 and 1200 milliseconds, inclusive. Very few measuring instruments respond quickly enough to allow direct measurement to the degree of precision desired. One of the more simple methods of measuring a current or voltage is to employ an indicator (oscilloscope) that responds quickly to the signal being measured, a means of storage (operator's memory) and a signal source, known to have good waveform, that may be substituted for comparison. (See figure D1.) In this method, it is required to know the accuracy of the current-to-voltage transducer ($\leq$ 1%), the accuracy of the voltmeter ($\leq$ 1%) and the precision with which the comparison can be made (< 1%).

2. A new current to voltage transducer is being permanently installed on the ground leg of the antenna tuning system. This device has an output of 0.01 volt per ampere and is accurate to < 1%. Its purpose is primarily to provide a means of accurately measuring antenna current in order to calibrate the panel meters in the Timing and Control racks. However, during field measurement activities, it will be used to provide antenna current data directly.

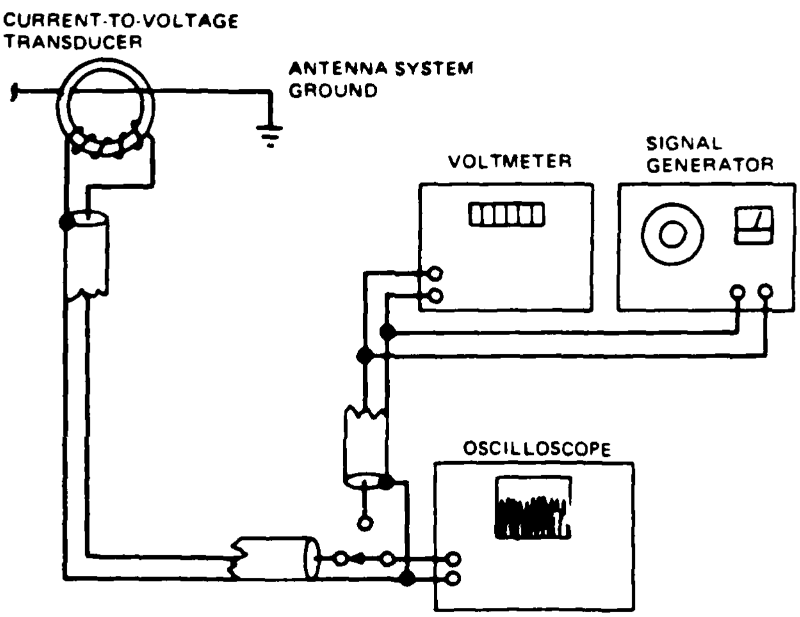


Figure D1

II. PROCEDURES

A. BASIC CURRENT MEASUREMENT

1. Assemble the equipment as shown in figure D1.

2. Set the frequency of the signal generator to 12 kHz.

3. Set the controls of the Tektronix 455 Oscilloscope as follows:

   a. Horizontal Display: A

   b. Trigger Mode: AUTO

   c. Coupling Source: AC-Normal

   d. A Trigger Level: 0

   e. A and B Time/Div: 1 ms, calibrated

   f. Vertical Mode: CH2

   g. Input Selector Switch: AC

   h. Vertical Position (CH2): Full down (CCW)

   i. Vertical attenuator and variable control: As necessary to position the top of the waveform being measured approximately 7 cm from the bottom of the screen. Check to be sure the signal is not limiting. If limiting occurs, change ranges and if necessary, use an external attenuator.

   j. Test the frequency response of the vertical presentation over the range of Omega frequencies to be sure that the comparisons may always be made at 12 kHz. (An error was once found, in an oscilloscope, over the range of 10 to 14 kHz.)

4. With the outut of the current-to-voltage transducer connected to the vertical input of the oscilloscope, adjust the oscilloscope as required by step 3i. Note the position of the top of the waveform being measured.

5. Without disturbing any of the oscilloscope controls, disconnect the transducer and connect the cable from the signal generator and voltmeter to the vertical input.

6. Adjust the output attenuator and variable control of the signal generator to produce a display of the same amplitude noted in step 4.

7. Read the voltage required in step 6 and divide the value by 0.01 to obtain the current in amperes. (Note that even though the comparisons are being done by peak measurements the voltmeter readings, in volts rms, are valid because the waveforms are essentially sine waves.)

8. Repeat steps 4 through 7 for each frequency being transmitted.

9. Record all the data required by Data Sheet 3 on that sheet. The time interval will be specified by the person in charge of the field intensity measurements.

B. CURRENT MONITORING FOR FIELD INTENSITY MEASUREMENTS

1. Set up the equipment as shown in paragraphs A1, 2, and 3 above.

2. Choose the one highest value of antenna current that will be possible to hold all day for all frequencies. Typically, this will be the maximum current that may be so maintained on 10.2 kHz.

3. Multiply this value of antenna current by the transfer factor of the current-to-voltage transducer to obtain the required output voltage from the signal generator. Adjust the signal generator to this value.

4. Connect the signal generator to the oscilloscope. Adjust the vertical gain control of the oscilloscope to place the top peaks of the waveform on the second highest horizontal line of the graticule. Do NOT change the vertical position control from the full down (CCW) position.

5. Switch the oscilloscope from the signal generator to the current-to-voltage transducer.

6. Using the individual and master attenuators of the Timing and Control Set, adjust the current of each frequency so the peaks of each waveform touch the same line chosen in paragraph B4. This ensures that all frequencies are at the same current and may be maintained there during the entire period of field measurements.

7. Periodically recheck the calibration of the oscilloscope as in Paragraph B4. Experience and the stability of the oscilloscope will determine the frequency of recalibration.

8. Using the procedure of this section reduces the amount of logged data and also the opportunity for error. Only the chosen current, or a new current if necessary, need be logged and time noted.

III. CONCLUSIONS

1. Procedure A is most useful during routine operation to verify the accuracy of the antenna current meters of the Timing and Control Set.

2. Procedure B is preferred during field intensity measurements because, in addition to the previously noted advantages, it simplifies the calculation procedures.

DATA SHEET 3

RADIO FIELD INTENSITY

ANTENNA CURRENT

DATE: ______________

OMEGA STATION: ______________________ SHEET NUMBER: ______

ANTENNA SYSTEM CURRENT (I_{as})

TIME (Local)	10.20 (kHz)	13.60 (kHz)	11-1/3 (kHz)	11.05 (kHz)	F_t ______ (kHz)

APPENDIX E: FIELD INTENSITY MEASUREMENTS BY HELICOPTER
(Revision 1)

I. INTRODUCTION

1. Some of the Omega stations are located in sites which are almost impossible to measure on the ground. These are either volcanic islands such as Hawaii and Reunion, the mountainous island of Tsushima, or the mountainous coast of Norway. These areas, besides being almost impassable, are characterized by poor and variable ground conductivity. These conditions dictate a measurement site remote from the poorly conducting ground plane and above the impassable terrain. Due to the low duty cycle pulses of the Omega signals a moving vehicle (fixed wing aircraft) is a very unattractive platform. The length of time required to obtain an accurate measurement requires a stationary platform. Above the terrain this means a helicopter.

II. INSTRUMENTATION

1. To reduce the pattern distortion, and consequent calibration factors, it is desirable to mount the loop antenna as far from the helicopter structure as practical, while placing the null of the antenna pattern directly on the largest noise source of the vehicle.

2. Each kind of helicopter presents its own set of mounting problems. It is practical to position the loop approximately five (5) feet from either side of the cabin. Additionally the loop should be mounted on the side opposite the tail rotor in case of a mounting failure. While the Hughes 500C helicopter produced no noise problems, with the loop mounted parallel to the longitudinal axis, other helicopters did. In these cases the loop was oriented to pick up the least noise from the helicopter. Since the Hughes 500C was available at both Norway and North Dakota, the mounting (to the steps) was designed to telescope and rotate while keeping the loop in a fixed position relative to the helicopter. Mounting to other helicopters must be arranged on site if a specimen is not available prior to departure. A rotating mount for the loop must be provided to allow positioning the null on the noise source. It is important that the mounting hardware be made of insulating material and the fastenings be nonmagnetic. The loop and mounting assembly must withstand forward speeds of 100 knots and also the down wash of the main rotor.

3. All wires and cables, associated with the loop assembly, must be secured in such a manner that they will withstand the airstream during flight. They should be spirally wrapped around tubular sections, of the loop mount, to aid in vortex shedding.

III. PROCEDURE

A. CALIBRATION

1. Calibration of the helicopter mounted loop must precede measurement flights. It should be done as near the station as practical in order to have a strong, noise free signal. The suggested distance would be 18 to 22 kilometres.

2. All the equipment necessary for field intensity measurements shall be aboard the helicopter. A tripod mounted loop antenna is placed about 15 metres from the

helicopter at a position that places the helicopter in the null of the antenna pattern when the plane of the loop is aimed at the station. Auxiliary cables, approximately 15 metres in length, are used to connect the tripod mounted loop to the measuring equipment in the helicopter.

3. Have the antenna current monitored and maintained, by the substitution method outlined in Appendix D, Section II B, and entered on Data Sheets 5 and 6.

4. Perform Field Intensity measurements, using the substitution method of Appendix C, with the tripod mounted loop. Record the readings on Data Sheet 5.

5. Transcribe the required values to Data Sheet 6 and, using 1.0 for K_3, calculate $E_r d/I_a$ for each frequency.

6. Disconnect the external antenna and connect the helicopter antenna to the measuring equipment.

7. Lift the helicopter off the ground and hover with the loop at the same height, and over the same position, as the tripod mounted loop. Swing the helicopter right and left to determine the direction of maximum signal. Do not try to get a null.

8. With the helicopter hovering in the direction of maximum signal measure all frequencies. Record the data on Data Sheet 5.

9. Transcribe the necessary data to Data Sheet 6 and, using 1.0 for K_3, calculate $E_r d/I_a$ for each frequency.

10. Divide the values determined in step 5 by the values determined in step 9 to obtain the true value of K_3, the Vehicle Correction Factor.

11. Repeat steps 7 through 10 with the helicopter pointed away from the station.

B. MEASUREMENTS

1. The determination of distance from the measurement site to the transmitting antenna is very important.

a. If a position can be found on a chart or map it may be described in terms of latitude and longitude or a grid system. Since coordinates of the transmitting antenna are known the distance may be calculated by great circle navigation equations or by rectangular to polar conversion.

b. Over water, over land which has few identifiable features, or over land at altitudes high enough to make visual positioning difficult, it is necessary to use radio distance measuring equipment to establish position. Any number of simple triangulation and vector addition calculations may be used to obtain the distance and azimuth of the measurement site from the transmitting antenna.

2. The altitude chosen for measurements is a compromise value – high enough to ensure readings unaffected by changes in altitude and low enough for accurate maintenance of position by visual reference. One thousand (1000) feet above the terrain has been selected for helicopter operations using visual position fixing.

3. The step-by-step procedure used to obtain a measurement follows:

a. Choose the location over which the measurement is to be taken. Note a sufficient number of landmarks to facilitate maintenance of the position.

Over water it might be advisable to drop a floating smoke generator or dye marker to provide a visual reference.

b. Tune in the Omega frequency having the longest duty cycle. Swing the helicopter (loop) plus or minus a few degrees about the estimated direction to the station to establish the direction of the maximum signal.

c. Point the helicopter in the direction of the maximum signal while hovering over the exact position of the site at the chosen altitude.

d. Perform the substitution type field intensity measurements on all the frequencies desired.

e. Most helicopters are difficult to control in a hover with the wind from behind. In some cases it will be necessary to use the tail toward the station orientation. Be sure to use the correct Vehicle Factor (K_3) for this direction.

APPENDIX F: REV. 1

MEASUREMENT OF ANTENNA TUNING SYSTEM GEAR RATIOS

I. INTRODUCTION

Gear ratios for the gear boxes of the Antenna Tuning Set were calculated under the assumptions that the required inductance change is an exact inverse function of frequency, that each variometer was operating in the same part of its travel and the inductance change is linear. In practice none of these assumptions are correct but provided a starting point to allow preliminary operation and test. After installation and preliminary operation, the necessity of adjustment of the calculated values becomes apparent. As the antenna capacitance changes, from any cause, the antenna tuning will attempt to keep all the frequencies tuned simultaneously. When the antenna capacitance changes, if the gear ratios are incorrect, there will be hunting back and forth as each frequency is keyed. This not only causes unnecessary wear in the tuning system components but, if the error is large, can prevent the antenna from being tuned during the short period of one transmission segment. The procedure reported herein allows selection of the best gear ratios from the sprockets available.

II. MEASUREMENT

A. EQUIPMENT

1. An adding and subtracting turns counter is mounted on the main drive right angle support frame in Room 101. This should be direct drive and indicate 1/10 turn of the shaft.

2. A switchable step capacitor is attached to the antenna near the exit bushing. If any prior knowledge of the excursion of the antenna capacitance is available, try to adjust the added capacitance to this value. If no prior knowledge is available, use the maximum capacity change that will allow the variometers to operate in the reasonably linear, or useful, range. The plate spacing, however, must be sufficient for the minimum voltage that will allow proper automatic antenna tuning. If the new switchable test capacitor is used, spacing gauge blocks are provided for 1, 1-1/2 and 2 inch spacings. Minimum spacing is approximately 1/2 inch and maximum approximately 2-1/2 inches. Table F1 gives estimated capacitances at various spacings.

TABLE F1

Spacing (inches)	Estimated Capacitance (pF)	Measured Capacitance (pF)
0.5	1000	------
1.0	520	585
1.5	360	405
2.0	280	322
2.5	230	272

B. PROCEDURE

1. Disengage all of the clutches, in the variometer rooms, except the clutch to the variometer gear box being tested.

2. Adjust the transmitter output to the minimum value that will allow good antenna tuning and will allow the servo motor to start running, in the proper direction, to retune the antenna when the test capacitor is switched in or out of use.

3. With the test capacitor switch OFF, allow the antenna to be tuned automatically.

4. Read the main shaft revolution counter and enter the number on the appropriate line of Data Sheet F1 Rev 1.

5. Change the test capacitor switch to ON and allow the antenna to be tuned automatically.

6. Read the main shaft revolution counter and enter the number on the appropriate line of Data Sheet F1 Rev 1.

7. Enter the difference in the two counter readings, without sign, on a line of Data Sheet F1 Rev 1 between the two counter readings. This column is labeled "Drive shaft rotation" in turns.

8. Change the test capacitor switch to OFF and allow the antenna to be tuned automatically.

9. Read the main shaft revolution counter and enter the number on the next appropriate line of Data Sheet F1 Rev 1.

10. Perform the same subtraction and entry as in step 7.

11. This completes one full cycle of readings and produces two (2) values of "Drive shaft rotation."

12. Repeat steps 3 through 10 until satisfied that a good mean value may be calculated.

13. Calculate the mean value of the column of numbers labeled "Drive shaft rotation." Enter the mean value on the appropriate lines of Data Sheet F1 Rev 1 and F2 Rev 1.

14. Repeat steps 1 through 13 for each frequency. If this test is being made at the same time as installation of 11.05 kHz connect the chain to the sprockets for 11-1/3 kHz. in the variometer room for 11.05 kHz. as a temporary measure.

15. Enter the actual gear ratios used for this test on appropriate lines of Data Sheet F2 Rev 1.

16. The Data Sheets of this appendix will probably be reproduced as tables in a report of this test.

III. CALCULATION

1. Multiply the MDSR by the installed gear ratio, or the ratio actually used for this test, to obtain the number of turns the lead-screw made to retune the antenna (LSR). Enter these numbers in the LSR column of Data Sheet F2 Rev 1.

2. Choose the LSR for 13.60 kHz as the value of LSR (Reference). See Note 1 of Data Sheet F2 Rev 1. Divide the LSR (Turns) by the LSR (Ref.) to obtain the value of the LSR Ratio. Enter this number in the proper column of Data Sheet F2 Rev 1 and the appropriate line of Data Sheet F4 Rev 1.

3. Calculate all of the possible gear ratios, using the sprockets that are available at the station, and tabulate in ascending order on Data Sheet F3 Rev. 1.

4. Assign the lowest available gear ratio, from Data Sheet F3 Rev 1, to 13.60 kHz on Data Sheet F4 Rev 1. Multiply this gear ratio by the LSR ratio, for each frequency, entering these new values on the line for the Required Ratio in appropriate columns of Data Sheet F4 Rev 1. Continue assigning higher values to the column for 13.6 kHz until the calculated value of gear ratio required for 10.20 kHz exceeds the highest gear ratio available.

5. Tabulate the nearest available gear ratio immediately under the required gear ratio. Calculate the errors for each frequency on each line. Select the line with the smallest peak to peak error as the selected set of gear ratios. Install the sprockets indicated, for each selected ratio as shown on Data Sheet F3 Rev 1, in the appropriate variometer room.

6. If there are enough sprockets, install pairs of these new sprocket selections in the spare variometer room (106). If not, try the selection having the next higher error for the spare variometer room.

DATA SHEET F1 REV. 1

Frequency (kHz)	ΔC (____ pF)	Main Shaft Counter Readings (Turns)	Drive Shaft Rotation (Turns)
________	OFF	NNN · nn	
			NN · nn
	ON	___ · __	
			___ · __
	OFF	___ · __	
			___ · __
	ON	___ · __	
			___ · __
	OFF	___ · __	
			___ · __
	etc.		

Mean drive shaft revolutions (MDSR) ___ · __

DATA SHEET F2 REV. 1

Frequency (kHz)	MDSR (Turns)		Installed Gear Ratio (2)		LSR (Turns) (2)		(1&2)		LSR Ratio between Frequencies (2)
10.20	NN·nn	×	N·nnnnn	=	NN·nnnn	÷	LSR (Ref.)	=	N·nnnnn
11.05	__·__	×	_·____	=	__·___	÷	LSR (Ref.)	=	_·____
11-1/3	__·__	×	_·____	=	__·___	÷	LSR (Ref.)	=	_·____
f_t	__·__	×	_·____	=	__·___	÷	LSR (Ref.)	=	_·____
13.60	__·__	×	_·____	=	__·___	÷	LSR (Ref.)	=	_·____

NOTE 1. While any one of the LSR values may be chosen it is easier to use the value of 13.60 kHz to produce whole number ratios for the next step.

NOTE 2. Even though the precision of measurement does not warrant it, keep at least 6 significant figures to avoid rounding errors.

DATA SHEET F3 REV. 1

Available Gear Ratios

Gear Ratio	Sprocket Teeth (Input-Output)	Gear Ratio	Sprocket Teeth (Input-Output)
0.61111	33-54		
0.63462	33-52		
–			
–			
–			
–			
1.44444	52-36		
1.45455	48-33		
etc.			

DATA SHEET F4 REV. 1

Required gear ratios

Available gear ratios

Peak to peak error of each selected set

Frequency (kHz)	13.60	ft	11-1/3	11.05	10.20
LSR Ratio	1.00000	1.46362	1.60990	1.70495	2.08270
Required Ratio	0.61111	0.89443	0.98383	1.04191	1.27276
Available Ratio		0.88889	1.00000	1.04167	1.22727
Error (%)	5.35 p-p	-0.62	+1.64	-0.02	-3.71
Required Ratio	0.63462	0.92884			
Available Ratio		0.92593	etc.		
Error (%)		-0.32			

NOTE 1. When making selections from a limited number of sprockets which are available it is possible that large errors will appear on some lines. Visual inspection will allow the calculation to be stopped on that line, saving some effort.

APPENDIX G: POSITION FIXING OF A VEHICLE BY RADIO DISTANCE MEASURING EQUIPMENT (DME)

I. INTRODUCTION

1. In order to calculate the radiated power of a transmitting station, it is necessary to make field intensity measurements (FIM) of the radiated signal and to precisely know the distance between the transmitting and measuring antennas.

2. The usual vehicle used to measure field intensity above the surface of the Earth is the helicopter because of its capability of remaining stationary over a position while many measurements are made.

3. Visual determination of the precise position at the usual altitudes of 300 to 1000 meters is very difficult. The use of general purpose forms of radio navigation is neither as precise or as fast as desired.

4. DME, such as the Trisponder manufactured by Del Norte Technology, is capable of producing suitable measurements that satisfy both the precision and speed requirements.

5. An additional on-board computer (programmable calculator) is required to calculate the distance and azimuth from the transmitting antenna.

II. REQUIREMENTS

1. For a number of reasons FIM, on frequencies in the 10 to 14 kHz navigation band, are conducted at distances of 20 to 40 kilometers from the transmitting antenna. To ensure a reasonable amount of accuracy in the final calculations, an attempt is made to limit each contributing error to a practical minimum.

2. The parameters measured to calculate radiated power are tabulated in order of increasing difficulty in measurement accuracy.

   a. Distance from the transmitting antenna

   b. Antenna current

   c. Field intensity.

3. At the measurement ranges, an error of ±0.5% is 100 to 200 meters. It should be easy to do better, probably near ±0.25%.

4. The azimuth must be known, to a lesser accuracy, to identify the radial direction of the measurement.

III. METHOD

A. INTRODUCTION

1. The method chosen consists of triangulation to locate the helicopter on a vector from a transponder location; and vector addition to locate the helicopter with respect to the transmitting antenna. This solves the problem for both azimuth and distance. All of the position

measurement is done in the helicopter; facilitating navigation to a position for FIM and ensuring simultaneous position fixing with the FIM.

B. RANGE SELECTION

1. Two transponder locations are chosen near the measurement area. Consideration is given to the "line of sight" requirement of the DME and to the geometrically acceptable operational area as shown in figure G-1. Figure G-1 is constructed as follows:

a. Using a drafting compass, set the drawing radius to the distance along the baseline.

b. Strike arcs above and below the baseline at intersecting points.

c. From the two intersecting points draw arcs, as shown in figure 1, between the transponder positions.

2. The operating area, for FIM along a radial, must fall in the area bounded by the arcs.

3. Check the coverage of the transponder antennas to ensure that the intended operating area is within the pattern angle. If using 180° antennas there should be no problem. With 90° antennas some of the geometrically correct area will not be covered.

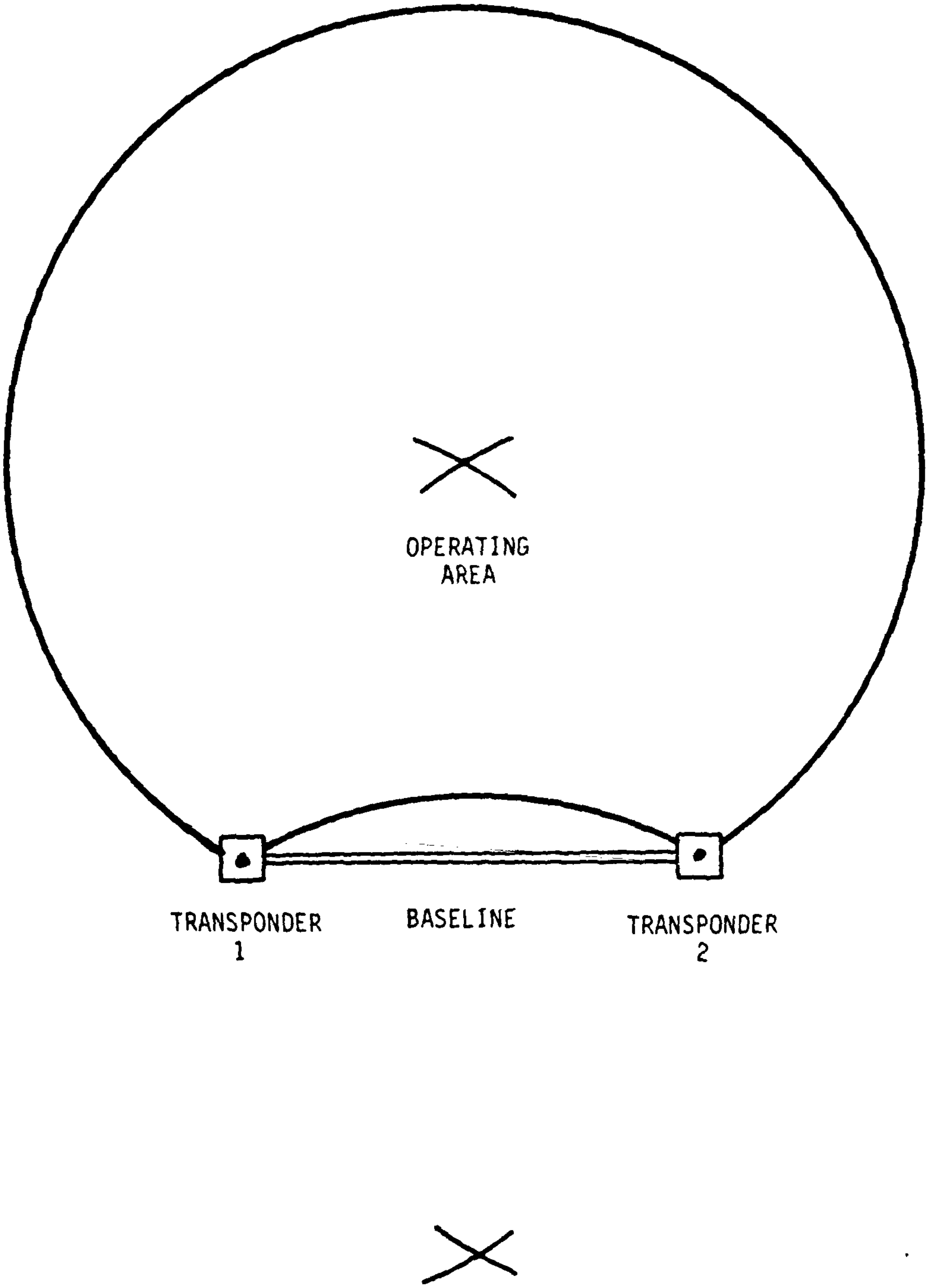


FIGURE G-1.

4. The transponder location nearest the transmitting antenna is usually defined as the primary and is used to obtain D1 on the distance measuring unit (DMU) in the helicopter. The transponder baseline is now the vector from the primary (D1) to the secondary (D2) transponder. Triangulation is done on this baseline.

5. The azimuth and distance from the transmitting antenna to the D1 transponder is the second vector and will be added to the D1 to helicopter vector.

C. PREFLIGHT PREPARATION

1. Select all transponder sites.

2. Calculate the transponder baseline azimuths and distances between all the transponder pairs to be used.

3. Calculate the baseline azimuths and distances from the station to the primary transponder of each pair.

4. If the positions of the transponders and the station are in grid coordinates, be sure to add the grid correction to obtain true North.

5. Record baseline data and solution steps on a program card of the on-board computer (calculator). Label the card and protect it against accidental erasure.

6. To check for gross errors, either in program or baseline data on the cards, it is advisable to perform a test position solution obtaining D1 and D2 by measurement on a map, checking the solution on a map.

D. FLIGHT PROCEDURES

1. After take-off, use deduced reckoning to navigate the helicopter to the proposed site of measurement. Deploy the DME antenna if required to be retracted while on the ground.

2. On estimated arrival at the site, measure D1 and D2. Calculate the position and give corrective directions to the pilot.

3. After confirmed arrival over the site, the pilot will pick a hover reference point and try to stay at the site. Over water, a marker (preferably dye) should be dropped in the water as a hover reference.

4. The DME should be allowed to run in the AUTO mode until a FIM reading is completed; then switched to MANUAL to lock the readings until they may be recorded.

IV. CALCULATIONS, ERRORS AND PROGRAMS

A. CALCULATIONS

1. In position determination by DME, the known values are the baseline azimuth, the baseline length and the two remaining sides of a triangle. The known values of the triangle are the three sides. The law of cosine is used to calculate the angle between the baseline and the vector to the helicopter from the primary (D1) transponder. This angle is added to the azimuth of the baseline to obtain the true azimuth from D1 to the helicopter. The distance to the helicopter from D1 is measured directly by the distance measuring unit (DMU) located in the helicopter.

2. To obtain the location of the helicopter, with respect to the transmitting antenna, the station to D1 vector is added to the D1 to helicopter vector. The resultant vector is the azimuth and distance from the station to the helicopter.

B. ERRORS

1. Several sources of error are present in this method of position fixing. They are, but not necessarily limited to, the following:

a. Errors in the maps used to determine the range parameters and in the locations plotted on them

b. Ranging errors by the DMU

c. Slant range versus true horizontal distance when the helicopter and transponders are at different heights

d. Calculation errors caused by using a finite number of significant figures, and

e. Errors in rounding off the calculated values to provide a practical display.

They may be minimized, disregarded as inconsequential, or accepted as a contribution to the total error.

2. Map errors of cartography are not known so are not considered. Errors in printing or caused by paper shrinkage may be corrected by measurement and calculation of a scale change. The use of precision calipers or dividers helps minimize the plotting errors. In any case, it

is estimated that a position may be located, on a map having a scale of approximately 1:25000, to a precision of ±10 meters.

3. The Del Norte Technology DME, after being calibrated on a test range, is expected to be within 3 meters of the indicated ranges at distances of 100 meters through 80 kilometers. It is claimed that, in practice, the error is most likely 1 meter or less at ranges of 150 meters to 70 kilometers. These errors are inconsequential.

4. Slant range errors may be kept to values small enough to be ignored by selection of the transponder locations. If possible, select positions as close as possible to the operating altitude of the helicopter. If this is not possible, keep the distance between the helicopter and the transponder large; for example, at 20 kilometers, with a difference in height of 500 meters. The error is 6.25 meters. Try not to allow the slant range error to exceed 10 meters. Of course, a powerful on-board computer can correct for slant range errors.

5. By using calculators or computers which perform calculations using 10 or more significant figures, instead of plotting position, the calculation errors are minuscule.

6. In the program to be presented later, the displayed azimuth is improperly rounded, which results in possible errors of almost 1 degree. Since the azimuth is only used to identify the radial direction, and the distance is properly treated, this is also unimportant.

7. In summary, the largest contribution to the total error is in locating the transponders by map interpretation. If it is possible to locate the transponders relative to surveyed benchmarks this source of error will be minimized. The second largest contributor, slant range, can be reduced by site selection, distance selection or increased computational power.

C. PROGRAMS

1. The only programmable calculator available to the author was the Hewlett-Packard HP-65. It has a limited number of program steps (100) and a limited number of storage registers (8), because of trigonometric functions.

2. The display desired gives the position of the helicopter in polar coordinates from the transmitting antenna, all on one display line. The distance is presented in kilometers and thousandths (1 meter resolution) and the azimuth in degrees, with a rounding error of 0 to -0.999-- degree.

3. Using the law of cosine, the angle between the transponder baseline (D1 to D2) and the vector from D1 to the helicopter is calculated. This angle is added to the baseline azimuth to produce the true azimuth of D1 to the helicopter. The true distance has been measured by the DMU as D1. The clockwise (CW) and counterclockwise (CCW) solutions refer to the position of the helicopter, with respect to the baseline, as viewed from D1.

4. The helicopter vector is added to the vector from the transmitting antenna to transponder D1.

5. The resultant vector gives the helicopter position.

6. This program runs in approximately 7 seconds which is sufficiently fast for on-board navigation. Other, more elaborate programs to correct for slant range errors, will probably run longer.

7. An additional feature that could be added, using a more powerful computer, would be for corrective navigation instructions to the pilot during the travel to a measurement site. The courses should be done in degrees magnetic to simplify the pilot's work.

8. Programmable calculators such as the HP-67 and HP-41C would have the capacity to do slant range and course correction.

9. The range data program is shown in Tables G1 and G2.

10. The position solution program is shown in Tables G3 and G4.

11. A sample range and position diagram is shown as Figure G-2. The range and position data is scaled directly from the grid of calculated using the Pythagorean Theorum with the exception of the azimuths of the two helicopter positions. These may be obtained by scale from the grid and use of trigonometry. This sample illustrates the precision of the program by independent calculation.

12. The notation "EX(N)" means the exponent of 10. This form is used because of the keyboard of the calculator used.

HP-65 User Instructions

Title: Position by DME - Range Parameters — Page 1 of 2

Programmer: J. C. HANSELMAN — Date: 20 Apr 1979

Range Parameters - Format	
LOAD	RCL 1
RCL 2	RCL 3
RCL 4	

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA UNITS
1	ENTER FORMAT CARD				
2	INITIALIZE POINTER		RTN		
3	SWITCH TO W/PRGM				
4	ENTER PROGRAM FOR LBL A AS SHOWN ON THE		LBL		
	REVERSE SIDE, ENDING WITH RTN.		A		
			etc.		
5	RECORD ON SIDE 2 OF A "POSITION BY DME" CARD		RTN		
	AND PROTECT. (TO TEMPORARILY STORE THE				
	COMPLETED PROGRAM, RECORD ON SIDE 2 OF THIS				
	CARD - UNPROTECTED)				
6	DO NOT KEY IN LBL's B, C, D, OR E. THEY				
	WERE ON THE FORMAT PROGRAM PREVIOUSLY ENTERED.				

Table G-1.

HP-65 Program Form

Title Position by DME - Range Parameters Page 2 of 2

SWITCH TO W/PRGM PRESS f PRGM TO CLEAR MEMORY

KEY ENTRY	CODE SHOWN	X	Y	Z	T	KEY ENTRY	CODE SHOWN	X	Y	Z	T
LBL	23					m					
A	11					m					
D						m					
.	83					m					
d						m					
d						m					
d						m					
d						m					
d						EEX	43				
d						N					
d						N					
d						STO 4	33 04				
d						f	31				
EEX	43					STK	42				
N						DSP	21				
N						9	09				
STO 1	33 01					RTN	24				
M						LBL	23				
.	83					B	12				
m						RCL 1	34 01				
m						R/S	84				
m						f	31				
m						STK	42				
m						RTN	24				
m						LBL	23				
m						C	13				
m						RCL 2	34 02				
m						R/S	84				
EEX	43					f	31				
N						STK	42				
N						RTN	24				
STO 2	33 02					LBL	23				
D						D	14				
.	83					RCL 3	34 03				
d						R/S	84				
d						f	31				
d						STK	42				
d						RTN	24				
d						LBL	23				
d						E	15				
d						RCL 4	34 04				
d						R/S	84				
d						f	31				
EEX	43					STK	42				
N						RTN	24				
N											
STO 3	33 03										
M											
.	83										
m											

REGISTERS

- R_1 TR1 → TR2 Baseline Az. (°T)
- R_2 TR1 → TR2 Baseline Length (m)
- R_3 STA → TR1 Azimuth (°T)
- R_4 STA → TR1 Distance (m)
- R_5
- R_6
- R_7
- R_8
- R_9

LABELS

- A LOAD
- B RCL 1
- C RCL 2
- D RCL 3
- E RCL 4
- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9

FLAGS

- 1
- 2

TO RECORD PROGRAM INSERT MAGNETIC CARD WITH SWITCH SET AT W/PRGM

Table G-2.

AD-A082 487 MEGATEK CORP SAN DIEGO CA F/G 17/7
OMEGA JAPAN ANTENNA SYSTEM: MODIFICATION AND VALIDATION TESTS. --ETC(U)
OCT 79 J C HANSELMAN N00123-78-C-0043
UNCLASSIFIED NOSC-TR-492-VOL-1 NL

2 OF 2
AD
A082487

END
DATE
FILMED
5-80
DTIC

HP-65 User Instructions

Title: Position by DME, Distance and Azimuth from Station — Page 1 of 2

Programmer: J. C. HANSELMAN — Date: 4 January 1979

Position by DME CW CCW (Program 2) | SPARE PROGRAM

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA UNITS
1	ENTER: RANGE PARAMETER PROGRAM CARD (SIDE 2)				
2	STORE RANGE PARAMETERS		A		
3	ENTER: POSITION BY DME PROGRAM CARD (SIDE 1)				
4	KEY IN: DMU 1	Meters	ENT		
	DMU 2	Meters			
5	EXECUTE IF VEHICLE IS CLOCKWISE (RIGHT)		A		
	OF BASELINE				
6	EXECUTE IF VEHICLE IS COUNTERCLOCKWISE (LEFT)		B		
	OF BASELINE				

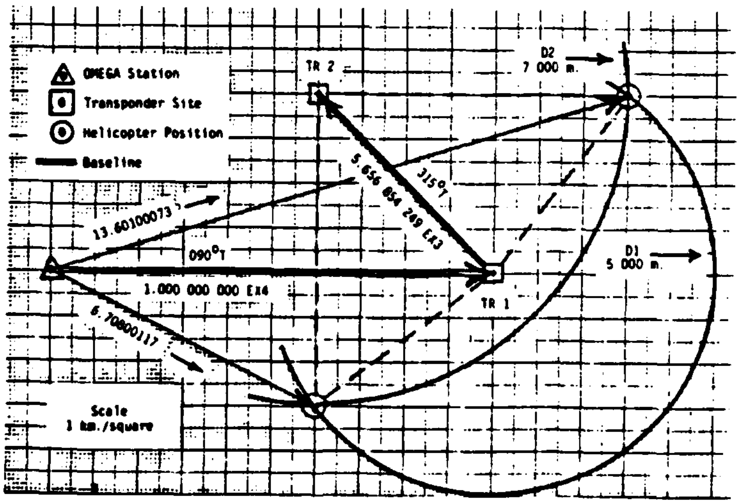


Table G-3.

HP-65 Program Form

Title: Position by DME, Distance and Azimuth from Station   Page 2 of 2

SWITCH TO W/PRGM PRESS f PRGM TO CLEAR MEMORY

KEY ENTRY	CODE SHOWN	X	Y	Z	T
LBL	23	KEY IN: DMU 1 (Meters)			
A	11				
D	14				
RCL 1	34 01	PRESS: ENTER↑			
+	61				
3	03	KEY IN: DMU 2 (Meters)			
6	06				
0	00				
g x≤y	35 22				
-	51				
g x⇄y	35 07				
g x⇄y	35 07				
STO 5	33 05				
E	15				
RTN	24				
LBL	23				
B	12				
D	14				
RCL 1	34 01				
g x⇄y	35 07				
-	51				
0	00				
g x>y	35 24				
3	03				
6	06				
0	00				
+	61				
+	61				
STO 5	33 05				
E	15				
RTN	24				
LBL	23				
D	14				
STO 8	33 08				
g R↓	35 08				
STO 6	33 06				
RCL 2	34 02				
f-1	32				
√x	09				
RCL 6	34 06				
f-1	32				
√x	09				
+	61				
RCL 8	34 08				
f-1	32				
√x	09				
-	51				
2	02				
÷	81				
RCL 2	34 02				

KEY ENTRY	CODE SHOWN	X	Y	Z	T
RCL 6	34 06				
x	71				
÷	81				
f-1	32				
COS	05				
RTN	24				
LBL	23				
E	15				
RCL 3	34 03				
RCL 4	34 04				
f-1	32				
R→P	01				
RCL 5	34 05				
RCL 6	34 06				
f-1	32				
R→P	01				
g x⇄y	35 07				
g R↑	35 09				
+	61				
g x⇄y	35 07				
g R↑	35 09				
+	61				
f	31				
R→P	01				
f	31				
INT	83				
EEX	43				
3	03				
÷	81				
g x⇄y	35 07				
0	00				
g x>y	35 24				
3	03				
6	06				
0	00				
+	61				
+	61				
EEX	43				
8	08				
÷	81				
+	61				
DSP	21				
·	83				
8	08				
RTN	24				

DISPLAY

MM.mmm00DDD

Distance (km)   Azimuth (°T)

Station to Vehicle

REGISTERS	
R_1	TR1 → TR2 Baseline Az. (°T)
R_2	TR1 → TR2 Baseline Length (m)
R_3	STA → TR1 Az. (°T)
R_4	STA → TR1 Distance (m)
R_5	B1
R_6	b
R_7	Not Used
R_8	c
R_9	USED

LABELS	
A	CW
B	CCW
C	
D	Δ SOL.
E	+ VECTOR
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	

FLAGS	
1	
2	

TO RECORD PROGRAM INSERT MAGNETIC CARD WITH SWITCH SET AT W/PRGM

Table G-4.

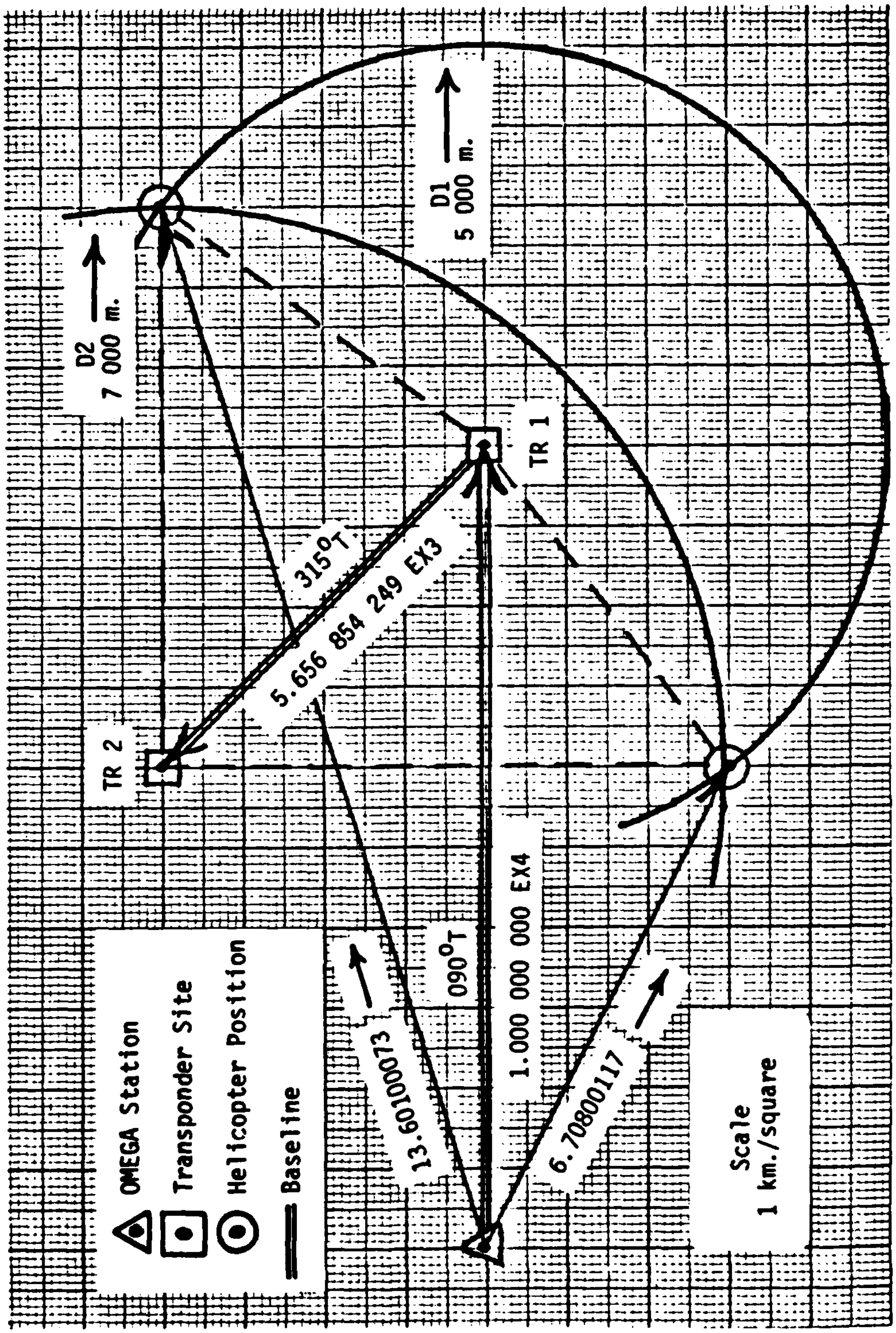

D1
5 000 m.
D2
7 000 m.
TR 1
TR 2
315°T
5.656 854 249 EX3
090°T
1.000 000 000 EX4
13.60100073
6.70800117
OMEGA Station
Transponder Site
Helicopter Position
Baseline
Scale
1 km./square

FIGURE G-2

APPENDIX H: EQUIPMENT FOR FIELD INTENSITY MEASUREMENTS

Equipment furnished specifically for field intensity measurements.

1. The equipments listed below were delivered to OMEGA JAPAN for retention and use in conducting future field intensity measurements.

Table H-1

Equipment	Mfgr	Model No.	Serial	Decal
Loop Antenna	Stoddart	94608-1	118	1727
VLF Tuned Amplifier	Megatek	LPA-1A	500298	1852
Signal Generator	Hewlett-Packard	204-D	05320	1748
Digital Volt-Ohm Meter	Fluke	8600A-01	0585160	1756
Current Transformer	Pearson	1114-4	2283-6	1783
Oscilloscope	Tektronix	455	B044150	1767
Battery Power Supply	Tektronix	1106	B023377	1775
Tripod	Leitz	7536-20	None	None
Twinax Cable (50 ft)	-	RG-108/U	None	None
Coax Cable (50 ft)	-	RG-58/U	None	None
Ext. Attenuator for LPA-1A	Megatek	None	None	None